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Roman mosaic glass: a study of production processes, using PIXE spectrometry

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Abstract

The most attractive Roman glass produced during the early part of the 1st century A.D. was *mosaic* ware – bowls and dishes molded from arrays of multi-colored canes that created abstract floral and geometric designs. Yet ancient literature tells us little about the organization of the glassworking industry in which such wares were produced. We have focused upon two kinds of mosaic decoration that include a component of white glass in their cane construction and have purple glass as their matrix. A consistent pattern in the minor levels of lead in each kind of glass suggests that they were the products of two separate workshops, each with separate sources of supply for their glass stock. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Our previous use of proton-induced emission [PIXE] spectrometry in the study of ancient glass has focused on the nature of its first production in northwestern Iran around 2200 B.C. and on the innovations in glass coloration that occurred in Egypt around the 14th century B.C. [1–4]. Our research emphasis has always been on optimization of detection sensitivity, in the face of the fact that it requires only small amounts of certain minerals – particularly those containing cobalt – to influence both coloration and/or hue. Such matters are discussed fully in Refs. [5,6], in connection with our development of different arrays of selective filters that enhance the detectability of trace elements in glass matrices. For the purpose of this paper, we note only that PIXE detection limits for the most common kinds of Roman glass – ones that are pale green or amber/brown, depending upon oxidation conditions during firing, and owe their coloration to the small amounts of iron which occur naturally in the glass' ingredients [7] – are usually close to those listed in Table 1.

With colored glass, however, where there may be a number of heavy elements present, generally higher backgrounds in some regions of the PIXE X-ray spectrum can increase detection limits quite a lot. Thus, in a white glass colored by calcium antimonate, the detection limit for SnO rises by

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Table 1
Typical PIXE detection limits for trace elements in soda–lime glass, using aluminum for selective filtering

Oxide	Detection limit (ppm)
3.8 mg/cm^2 Al foil	
TiO_2	25
Cr_2O_3	50
MnO	150
5.7 mg/cm^2 Al foil	
CoO	90
NiO	35
CuO	35
ZnO	70
As_2O_3	35
Ag_2O	60
SnO_2	180
Sb_2O_5	360
PbO	35

about 60 ppm for each additional percent of Sb_2O_5. Similarly, in a glass that contains a substantial amount of lead, the detection limit for As_2O_3 rises by about 280 ppm for each additional percent of PbO.

2. Roman mosaic glass

During the reign of Augustus (27 B.C.–A.D. 14), many skilled glassworkers were taken from Syria and Judaea as slaves and shipped to Italy. Roman businessmen put these craftsmen to work in large workshops, so that they could mass-produce glass tableware using the traditional Hellennistic technique of casting over a mold [8]. The range of these workshops' products initially was quite limited, in terms of size and shape, suggesting some degree of standardization was being applied. A far greater variability was accepted in the coloring of these wares. Emerald green and dark peacock blue were most fashionable among monochromes; polychromes were created by the blending together of hundreds of thin disks sliced from multi-colored composite canes. These polychromes are now called mosaic wares.

The two vessel fragments shown in Fig. 1 are typical examples of the design motifs of Roman mosaic wares that were based on a matrix of purple glass. The depth of coloration varies a great deal, to a large extent being dependent on the thickness of the vessel, particularly where there is a heavy ribbing on the outer surface. Quite what the inspiration for these design motifs might have been is unclear. Unlike vessels with an amber matrix full of swirling white bands that mimicked the appearance of expensive items carved from onyx stone [9], these purple-colored wares have no mineralogical parallel.

The technical ideas underlying such glass' manufacture – the fusing together of sections, segments, or lengths of pre-formed canes – are well known [10]. So too is their main period of production: archaeological excavation clearly indicates that it was the first few decades of the 1st century A.D. [11]. Where such vessels were made, however, is quite uncertain. They have been found at places as distant from one another as a cemetery at Ed Dur, in Bahrain, and a fort on Hadrian's Wall, in northern Britain [12]. Some historical records, including a remark made by the Augustan geographer Strabo (in *Geography* XVI.2), do point towards Rome as one center for mosaic glass production. But the movement of skilled craftsmen, glassworkers included, was quite common in the Roman world. In principle, a glass workshop could be set up wherever there was a ready access to glass stock – either freshly purchased ingots, or glass fragments recycled from broken vessels [13] – and wherever there were ample supplies of wood for fuel.

Among purple mosaic wares, we have identified two quite different, but relatively common design patterns and have coded them as follows:

bwr (basic white rods): The vessel was cast from a montage of slices cut from a fused cluster of purple and white glass rods. Dependent upon which direction the cluster was sliced – radially or longitudinally – the mosaic would have the appearance of showering tendrils (Fig. 1(a)) or thickly-layered bands.

cgr (compact green roll-ups or rosettes): The vessel was built up from prefabricated thin canes (typically only 6 mm across) that had been extruded from a more massive glass mass which comprised a sheet of green glass wrapped around

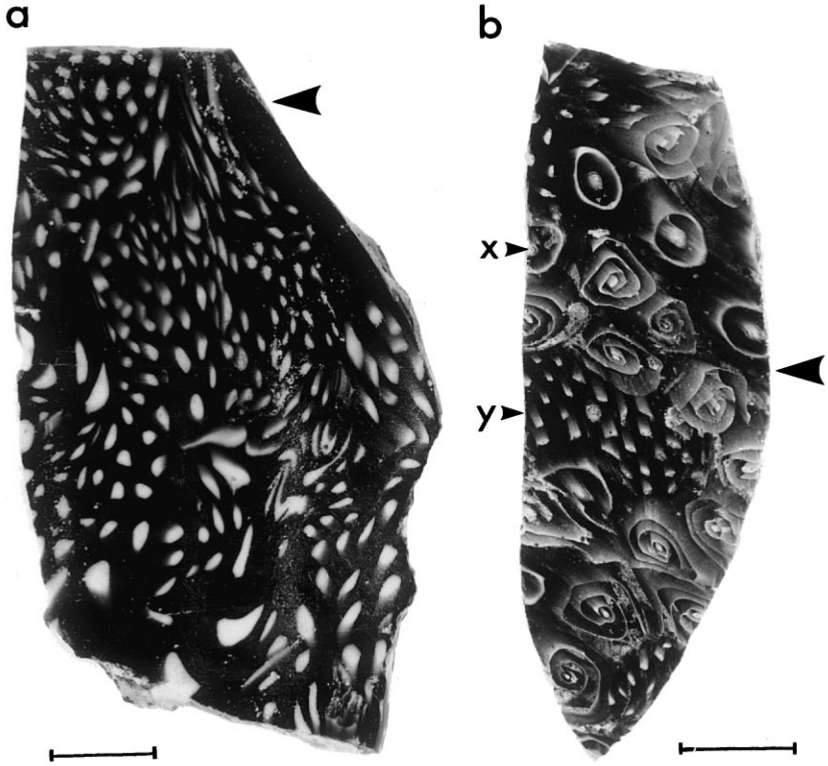

Fig. 1. Two sherds of Roman glass tableware, each with a purple matrix but with different decorative patterns (see Section 2): (a) type *bwr* (ribbed bowl, inv. 5387a); (b) type *cgr* (shallow dish, inv. #5383b). (Scale bar: 10 mm). Each sherd was lightly abraded on an edge (marked with a thick arrow here) to remove the weathered surface where some elemental dissolution might have occurred during the glass' period of archaeological burial [9] (Photography: H. Fred Scoch, University of Pennsylvania Museum).

a thick white rod (Fig. 1(b)). We have included in this *cgr* group other mosaic vessels which were built up from thin canes in the form of a rosette (as green petals around a white center) because they usually share two other design motifs – a white "bull's-eye" and a small cascade of yellow rods – in their overall design (see Fig. 1(b)), arrows x and y).

Did the obvious differences in the appearance of these two mosaic ware types necessarily mean they were from quite separate workshops? In terms of the PIXE analyses undertaken, such a question called for evidence that any elements – major, minor, or trace – vary consistently enough to serve as "fingerprints" for some step in the production process of either the purple or the white components of each ware type.

3. Compositional studies

The PIXE data for the primary constituents of these mosaic glasses are summarized in Table 2. Immediately, it is clear that the bulk composition of the two ware types are the same, and that each owe their purple coloration to the presence of the addition of similar levels of manganese and iron (MnO, circa 3.9%; Fe_2O_3, circa 1.3%). In the naturally-colored amber glass of "onyx" wares mentioned earlier, MnO and Fe_2O_3 contents usually would be much lower: circa 0.040% and 0.36%, respectively [14]. The possibility that the relative amounts of manganese and iron might be source-specific can be discounted, since the MnO/Fe_2O_3 ratios for the two ware types – 4.03 ± 1.27 (*bwr*) and

Table 2
Primary constituents of purple and white glass in Roman mosaic wares. Mean oxide content (wt.%)

Color	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	Sb_2O_5	MnO
Purple									
Type *bwr* ($n=13$)	15.0	0.91	2.13	73.3	1.28	10.7	1.06	0.16	3.71
S.D.	±3.4	±0.37	±0.25	±4.2	±0.26	±1.8	±0.55	±0.19	±1.13
Type *cgr* ($n=9$)	14.3	1.13	2.10	71.3	1.67	11.4	1.59	0.21	4.08
S.D.	±2.5	±0.83	±0.39	±5.6	±0.29	±1.1	±0.58	±0.12	±0.85
White									
Type *bwr* ($n=13$)	10.2	0.88	2.16	64.5	1.08	10.9	0.87	5.9	0.91
S.D.	±3.2	±0.15	±0.83	±6.2	±0.24	±2.5	±0.35	±3.3	±0.76
Type *cgr* ($n=4$)	10.8	0.54	2.29	54.9	1.12	8.2	1.36	9.2	1.38
S.D.	±4.1	±0.12	±0.83	±6.5	±0.26	±1.9	±0.39	±2.7	±0.36

2.69 ± 0.54 (*cgr*) – have appreciable scatter and statistical overlap.

A similar comparison of these ware types through their various minor and trace oxides listed in Table 1 also yielded a general compositional overlap. In preparation for the interpretative discussion in Section 4, we note particularly that manganese-rich minerals added to create purple coloration did not carry with them a significant amount of antimony. The typical Sb_2O_5 content of *bwr* purple glass was 0.16% (ranging $\leqslant 0.019\%$ to 0.60%), and of *cgr* purple glass was 0.21% (ranging $\leqslant 0.061\%$ to 0.46%): that of naturally-colored, amber glass was 0.13% (ranging $\leqslant 0.050\%$–0.33%: see Ref. [14]). There was, however, a statistically-clear point of separation among the lead contents (Fig. 2). For *bwr* wares, the PbO level was always less than 640 ppm ($n=13$): for *cgr* wares it was consistently much higher, ranging from 0.36% to 1.77% ($n=9$).

A similar assessment of PIXE data for the white glass in these purple mosaic wares yielded much the same story. Museum requirements that the analysis of all this glass be non-destructive meant that each of our PIXE analyses had to be carried out on an already fragmented edge (see Fig. 1). This limited the number of whites that we could report upon here to 17 (versus 22 for their purple matrices: see Table 2). Nonetheless, we were able to establish that: (i) in their main ingredients, *bwr* and *cgr* wares are indistinguishable (Table 2); and (ii) in their minor and trace elements, again the only thing that distinguished these ware types from

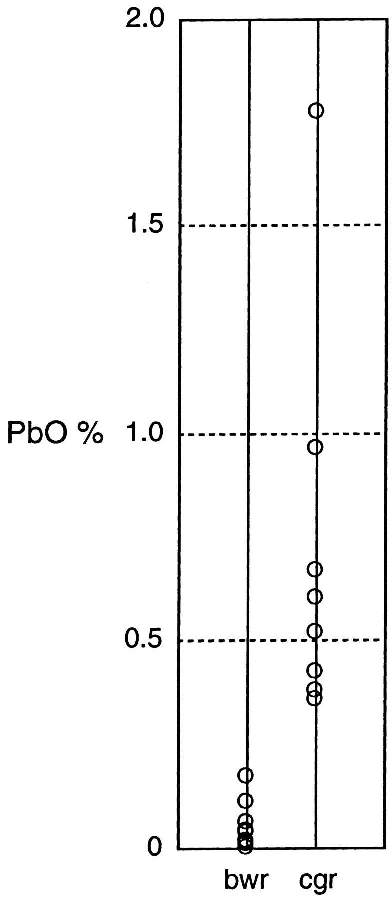

Fig. 2. A comparison of the lead oxide content in the purple glass matrix of *bwr* and *cgr* wares (Graphic: P. Zimmerman, MASCA).

one another was their lead contents. For *bwr* wares, PbO levels that were consistently low, ranging $\leqslant 0.0018\%$–0.078% ($n = 13$): for *cgr* wares, they were consistently much higher, ranging 0.84%–11.4% ($n = 4$).

4. A cultural interpretation

These data might, at first glance, seem to have a simple interpretation – for *cgr* wares, either by chance or by intent, some white glass was invariably mixed in with the purple glass during the vessel's manufacture. Such an interpretation would predict, however, a pro rata elevation in the levels of Sb_2O_5 in each *cgr* purple. We have no evidence for such an elevation (Table 3). For example, for the *cgr* ware 5383c, the relative proportions of PbO and Sb_2O_5 are 1:1 in its white glass, but 3:1 in its purple glass.

This situation directs us away from the glass*working* stage for vessel manufacture. Our data requires that the lead we have detected here entered the purple glass*making* stage: at a time when that glass first was being prepared from raw ingredients. We are then looking at the day-to-day operations of a workshop which routinely produced ingots of a lead-rich, calcium antimonate glass, and that some of the available lead-rich mineral – most likely, an oxide such as litharge (PbO) or red lead (Pb_3O_4), though possibly raw metal was used on occasion [15] – got caught up by chance in a parallel production of purple glass in the same workshop.

Table 3
Lead and antimony contents of *cgr* wares[a]

SHERD	Oxide content (wt%)			
	Purple		White	
	PbO	Sb_2O_5	PbO	Sb_2O_5
5383b	0.96	0.27	8.3	8.6
5383c	0.43	0.14	11.3	11.2
5383e	0.60	0.25	5.2	5.6
5387j	0.24	0.36	0.84	11.4

[a] Identified by the inventory number at the University of Pennsylvania Museum.

There are several reasons why ancient glassmakers might bring together lead and antimony. Usually, it was to create a bright yellow glass. By proper control the furnace environment, however, the glass could be kept white and thoroughly opaque, as the lead increased the solubility of the antimony oxide at high temperatures, and so encouraged it to precipitate out as crystals [16]. Since the addition of lead to a soda–lime glass softens it, the production of lead-rich white glass in Roman times is thought to have been encouraged by the needs of cameomakers who wanted to carve minute detail into the decoration of vessels such a the famous *Portland Vase* [17]. Cameo-making workshops were specialized placed in Roman times: perhaps *cgr* ware workshops were specialized as well. Both received their glass stocks from an equally specialized glass*making* center.

Lead-free calcium antimonate white was common enough among Roman mosaic glassware based on other matrix colors. (For example, among our own PIXE analyses of of white glass in onyx wares, the PbO levels are consistently less than 0.36% ($n = 35$)). A cluster of white rods also is one of the most common decorative patterns used in such glassware. So we would infer that *bwr* ware workshops most likely were *not* specialized: nor was the glassmaking center that supplied *their* stock specialized either.

We lack the Roman technical literature that might place these ideas in a firmer historical context. What we can say, however, is that we could not have attempted such a reconstruction of this kind of ancient production process without the unique advantages of detection sensitivity and spatial resolution that only PIXE spectrometry provides.

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