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BAUBLES, BANGLES AND BEADS: RECYCLING COLOURED GLASSES IN THE BRITISH IRON AGE AND ROMAN PERIODS

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ABSTRACT

Compositional analysis has proved to be a powerful tool for investigating the recycling of transparent glass in the Roman and Byzantine periods. This paper expands the focus further, to explore the recycling of coloured and opaque glass in the Late Iron Age and Roman periods in Britain. A review of the findings to date, predominantly for beads and bangles, illustrates how a combination of methods is needed to identify when coloured glass has been recycled and altered in the past. Chemical analysis, microstructural examination and experimentation have been used to understand how coloured glass was mixed, diluted and modified with novel colourants and opacifiers, in ways that are not apparent from non-destructive chemical analysis alone. The paper discusses possible types and sources of trade glass, the challenges of recycling monochrome and polychrome glass in different colours, and the unconventional methods used by glassworkers on the periphery of Roman influence to extend and modify coloured glass to produce distinctive items in order to express their identity.

KEYWORDS

Glass, Iron Age, Roman, colour, opaque, recycling, Britain, microstructure, analysis

INTRODUCTION

We tend to think of recycling as a modern phenomenon, but it is well evidenced that re-melting, recycling and reusing of glasses has been practiced in some form from almost as early as glass was produced (Jackson and Nicholson, 2010). The motivations for recycling today are to reduce manufacturing costs and waste and to ‘save the planet’. However, in the past glasses were often recycled because glass was rare, of high value and special significance, and because the raw materials used to produce early glasses were found only in a small number of locations and not readily available. Most artisans probably did not have the requisite knowledge to make a glass, but a greater number certainly knew how to manipulate it, and knew its properties made it eminently suitable for re-melting and reuse. Recycling has been a focus of many studies in recent years, mostly concentrating on transparent colourless and naturally-coloured Roman and Byzantine glass, where the mass production and the widescale distribution of finds has provided an extensive database to examine (Foy et al., 2003; Paynter and Jackson, 2016; Freestone, 2015; Schibille et al., 2017).

The focus of this paper is glass recycling in Britain– from approximately the first century BC to around the second century AD – and particularly for coloured and opaque glass. The Iron Age to

Roman transition in Britain is a creative period, when supplies of glass to the province were increasing. The first century BC is often seen as a turning point in terms of material culture and of continental exchange (Haselgrove, 1982) although the latter diminishes by the early first century AD. Whilst for some of this period parts of Britain were under Roman influence, other parts (Scotland and regions of northern England), whilst touched by Roman trade, manufacturing and at times peoples, were essentially not included in what might be considered the extended Empire. Similarly, this was a period of fluctuation and redefinition of identities where different artefact styles and materials were in a period of readjustment and change (Foulds 2014, 406). Thus, the different political geography of the land mass also needs to be understood to place different levels of glass use, artefact production and recycling into context.

There is a striking difference between the glass artefacts from Iron Age Britain relative to those from Romano-British contexts and further chronological and regional variation amongst the assemblages within those periods (Price and Cottam, 1998). The earlier glass finds are made in strong contrasting colours such as dark blue, purple, green, red, and opaque white and yellow, and are often opaque. The typical colourants are cobalt for deep blue, copper for red, green and sometimes turquoise blue, antimony in conjunction with lead for yellow and with calcium for white, and manganese to make purple. Such highly coloured glasses continue to dominate most artefact types up to about the first century AD, after which mass produced, blown glass vessels come to dominate made with transparent glass, either naturally coloured (with a muted blue-green tint) or colourless. The glass itself was made on a vast scale at tank furnace installations concentrated in the eastern Mediterranean region particularly Israel and Egypt (Brill, 1988; Nenna 2015) . There remained a demand for bright colours for certain applications however, particularly those used in items for personal adornment (Foulds, 2014; Ivleva, 2020; Henderson, 1991a).

The range of objects made in glass also changes over time. In Late Iron Age Britain the glass reworked and hence consumed in craft practices was mainly in the form of small items of coloured glass such as beads and inlays – coloured glass vessels were imported but they are unlikely to have been made here (Guido, 1978; Henderson, 1982; Price, 1988; Stevenson, 1956; 1976). From around the mid first century AD, there is also some evidence for specialist production of distinctive glass bangles decorated with coloured glass (Campbell, 2008; Ivleva, 2020) and more use of enamels (Davis, 2015).

This paper discusses examples of recycling involving coloured glass in Late Iron Age and Roman Britain, but here recycling is not just described in terms of re-melting and re-shaping of glass: it may also involve the alteration or modification of the glass, and the reuse of other waste products as a raw material. In this way recycling can mean a myriad of different things, and the term takes many different meanings at different times and in different contexts, and this is explored below.

BACKGROUND

Glassmaking

It is now well established that there was no primary glassmaking in Britain at this time, and so imported glass, as both ingots and finished artefacts, were used to manufacture new items. Glass found in Britain in this period is a soda-lime silica glass, made from a natron soda source obtained in the eastern Mediterranean, probably Egypt, and sand which could potentially have originated from a variety of locations, although analytical work suggests the primary sands used were from around the eastern Mediterranean too.From at least the first century BC, the raw materials were melted in very large tank furnaces which could hold up to 20 T of glass in a single melt (Nenna, 2015; Jackson et al., 2016). This glass was then redistributed more widely to glass working centres. Archaeological evidence for earlier glass manufacturing is ephemeral and it has been suggested that it may have been much smaller scale before the first century BC (Henderson, 2013, 94). The Roman large-scale industry would have developed from the earlier smaller scale tradition, in each region, expanding as demand for glass grew with the Roman Empire, and glass production became absorbed into this new political structure.

It has been demonstrated through compositional and isotopic analysis that there were two main types of transparent natron glass produced on a large scale throughout the Late Iron Age and Roman periods (although there was also variation within each of these glassmaking traditions (Foy et al., 2003)):

1. Glass with higher lime and alumina, derived from the sand, and decolorised or a blue-green colour modified with dissolved manganese. This was produced and widely exported from the Hellenistic period and its manufacturing location has been pinpointed to the Levant.
2. From at least the first century AD Egypt produced natron glass on a similarly large scale, but with lower alumina and lime, and decolorised with dissolved antimony.

Through re-melting and recycling of these glass types described above the compositions become mixed, and this can be identified when transparent glasses contain both antimony and manganese (Jackson and Paynter, 2016, 2021).

Making coloured glass

Some types of early Roman coloured glass may have been coloured during primary production (possible examples are amber glass, and Egyptian green glass (Paynter and Jackson, 2017; Jackson and Cottam, 2015)) but a lot of coloured glass was probably made at specialised secondary workshops, and especially strongly coloured opaque glasses (Freestone and Stapleton, 2015). To make coloured glass, transparent naturally-coloured or colourless natron glass (whether fresh or recycled) was melted down and colourants were added to it. This coloured glass could then be formed into rods, or cakes, or broken into chunks and potentially transported to other workshops for shaping into objects. Fragments of chunks, cakes or rods of coloured glass have been found, although rarely, at sites across Britain. The final composition of coloured glass is therefore a combination of:

- The transparent colourless or naturally-coloured base glass (whether Levantine, Egyptian or a recycled mixture)
- And the minerals or metals added to create the colour and/or opacity.

The composition of both the base glass and the types of colourants and opacifiers used change over time, and in different regions. These glass compositions are often time limited and have a particular lifespan, which may be related to the lifespan of the manufacturing centre or a change in trade routes to particular centres, political boundaries or other events. For example, Late Iron Age glass assemblages in Britain tend to be dominated by glass made in the Levant region until around the mid-1st century AD, at which point compositions more typical of Egyptian production become increasingly widespread (Jackson and Paynter, 2016). It is therefore possible to estimate the date of a glass, whether before or after this transition, from its composition, and the reuse of redundant compositions in later periods can also be another indicator of recycling. This can be observed at Culduthel where it is tentatively suggested that a blue glass bead may have been made of an earlier low alumina composition (Davis and Freestone 2018, 125). These highly coloured glasses, which probably were high status commodities, may have been in circulation for long periods of time and some colours of glasses may have been more difficult to obtain than others.

Colourants

Glass colouring would have been a specialist activity, probably restricted to certain production sites and workshops and produced to consistent recipes, and this is reflected in the very similar compositions of most coloured glass at a particular time. A degree of specialism was called for because there are unique difficulties to making and working coloured glass:

- Many colourants are based on minerals that are only found in certain regions and that need technical skills to prepare.
- Many colourants are not stable in the glass, and if prepared or worked incorrectly, then the colour of the glass will spoil.

The producers of coloured glass would be reliant on access to the minerals used as colourants, such as cobalt and antimony, which are only found in a limited number of locations worldwide (Gratuze et al., 1992; Shortland, 2002). Specialised knowledge and skill were also required, as particular minerals sometimes had to be combined with others in set ratios, added to a certain base glass in exact proportions and then heat treated in a precise way, to produce a specific colour (Foster and Jackson 2005, Lahlil et al. 2008, Molina et al. 2014). Overheating, too much stirring, the wrong rate of cooling, or oxidising might all spoil the colour, and this has implications for artisans later trying to recycle coloured glass.

Cross craft interaction, when high temperature technologies share similar locations and sometimes skills and materials, is commonly observed with glass, particularly the connections between the production of copper alloy objects, glass inlaying or enamelling and glassworking. It is likely that copper alloy working waste was used as the colourant in some colours of glass, because the common alloying metals tin and lead are often detected with the copper. This includes turquoise blue glass (Fredrickx et al., 2004) and possibly dark green glass (Bertini et al., 2011; Jackson and Cottam, 2015). Possible links between the waste from silver refining processes and red glass have also been considered (Freestone et al., 2003; Mass et al., 1998).

Glassworking and recycling

The glass artefacts themselves were not necessarily produced at the main glassmaking centres or specialist colouring workshops. Chunks, cakes or rods of glass were transported far afield for re-melting and shaping into objects, and glass objects (cullet) were also collected for recycling and there is ample evidence for this in the later Roman period (Jackson and Paynter, 2021).

However, the nature of glass trade, working and recycling prior to the mid first century AD is less well understood. The archaeological evidence from Britain suggests beads and bangles were the focus of production in this transitional period. Although production evidence is often ephemeral, typological, spatial and analytical studies however suggest that some classes of glass bead and the majority of glass bangles found in Britain were also made here (Henderson, 1982; Bertini et al., 2011; Paynter et al., 2022). These must have been shaped from pre-existing glass which could arrive in Britain in various forms. One of the easiest ways to produce a small artefact, such as a bead or bangle, would be to recycle another bead or bangle or other fragment of glass, and potentially change its shape through low heating, carving or adding other elements to it. As glass would have been relatively scarce and highly prized, glassworkers became adept at reworking the material. Clear evidence for sites manufacturing beads or bangles in the Late Iron Age or Roman period in Britain are scarce. Those tentatively identified include Culbin sands and Culduthel in Scotland, where it is suggested that beads, inlays or enamels were produced from melted fragments (Henderson, 1982; Davis and Freestone, 2018). At Culduthel evidence of probable working is in the form of a twisted spiral of blue and white glass, and a small composite thread of twisted yellow and colourless glass melted against a lump of opaque red glass. At Traprain Law in Scotland and Meare, Somerset, the large number of bangles and beads respectively suggest local production (Guido, 1978, 32) although this has been challenged (Foulds, 2014, 292). Analyses of the glass assemblages from these and other possible Late Iron Age glassworking sites, spanning south western Britain, northern eastern England and eastern Scotland, have indicated a renaissance in glassworking around the mid first century AD with the focus on beads and in some regions bangles in a range of colours and elaborative styles; similarly some bronze objects featured inlaid red glass, later combined with yellow glass.

Working of coloured Roman glass continued into the 2nd century AD. The bangle manufacturing site at Thearne, North Yorkshire has uncovered manufacturing waste in the form of droplets of glass, parts of canes and quite a high proportion of vessel glass, some of these associated with a furnace or oven structure (Campbell, 2008). Some of the canes recovered are in strongly coloured glasses and clearly show evidence of working as the ends are pinched or show pincer marks where the tools would have gripped the glass on application to the bangle body.

AIMS

The recycling of transparent colourless and naturally-coloured Roman glasses has been identified in a number of different ways; at manufacturing sites where debris is clearly evident, by examining glass types and compositions, and in the compositional fingerprints of ancient glasses (Paynter and Jackson, 2016). This paper focuses on the evidence for the recycling of *coloured* glass. Different mechanisms for identifying recycling have to be adopted in addition to the chemistry because, with the introduction of mineral colourants and opacifiers, a new suite of impurities is introduced into the glass which makes identification of recycling more difficult from the composition alone. Therefore, a combination of chemical, microscopic and microstructural techniques has been used to demonstrate recycling, and the introduction or mixing of different materials, glasses or additives, or even to demonstrate the novel techniques used to reform the glass, focussing on the 1st and 2nd centuries AD.

Several aspects of glassworking are discussed:

- Types and sources of trade glass
- Recycling objects – monochrome and polychrome
- Extending coloured glass – dilution and composite manufacture

- Novel colourants

MAKING THINGS

Traded fresh glass

Chunks, rods and cakes of coloured glass, in a form suitable for trading, have been identified at sites across Britain, albeit relatively rarely. In the Late Iron Age, red glass was found at Culduthell, and the authors suggest from the consistency of the chemical composition of the fragments that these may have derived from a single ingot as the vivid red colour produced by dendritic crystals in the glass would not withstand repeated melting without losing its opacity and colour (Davis and Freestone, 2018, 120). These red glass compositions are typical of those made in the Levant although they appear to be contaminated with refractory material and may have been coloured away from source (Davis and Freestone, 2018, 122). The use of ingots for the opaque yellow glass for bead production is also proposed and there is a reported chunk of blue glass from Hengistbury Head (Guido, 1978, 29; Henderson, 1987).

From the early Romano-British period, evidence is more plentiful, including some coloured glass in the form of cakes and lumps (Paynter et al., 2015; Bayley, 2015). Small chips of blue glass and canes of glass have been found at the bangle-making site at Thearne, although these may not be fresh glass. There is also evidence for the import of raw colourless and naturally-coloured glass to Roman London (Wardle et al., 2015). Naturally-coloured blue-green glass was used for the bodies of some bangles and many Iron Age beads (Henderson and Warren, 1981; Paynter et al., 2022) and it is possible that some of these were also manipulated from raw glass, especially when their composition does not indicate obvious signs of recycling.

Recycling and reusing artefacts – shape shifting and appropriating

Perhaps the most common form of recycling is the same as practiced today – that of re-melting a variety of broken artefacts, or cullet, most commonly in transparent glass. This is extremely common in Roman contexts and probably accounts for most of the naturally-coloured blue-green glasses found in Britain and on Roman-period secondary working sites (Jackson and Paynter, 2021). It also seems to have been a common occurrence in glasses reworked in Late Iron Age contexts. In a recent study, the colourless and naturally-coloured glass used in the body of many bangles contained both manganese and antimony oxide (Paynter et al., 2022).

Monochrome coloured glass items, such as bowls and tesserae, were also potential glass sources; some tesserae were recycled for enamelling (Cool and Price, 1998; Bayley, 2015) and may have been recycled for bangle and bead production. Tesserae were found widely throughout the empire, they are very portable, easy to collect, and perhaps most importantly highly coloured. There has been suggestion that the blue glass flake found at Culduthel may have derived from a fragment of tesserae, its lead and antimony concentrations share those found in tesserae (Davis and Freestone, 2014, 125). The copper blue decoration on Type 2 bangles from Thearne also mimics the composition and microstructure seen in tesserae (Paynter et al., 2022). Conversely, some tesserae were made by cutting down coloured glass vessels (Figure 1), demonstrating recycling by means of cold, rather than hot, working which could be undertaken without the need for specialised equipment or knowledge.

These examples demonstrate clearly the recycling of monochrome glass objects, but there are also many glass objects from the Late Iron Age and 1st and early 2nd century AD Romano-British contexts that are polychrome. This includes imported cameo, pillar moulded, mosaic and marbled vessels, as well as objects made in Britain, such as beads and bangles with coloured trails and cords; there is growing evidence that these polychrome objects were also recycled. The white glass of cameo or pillar moulded vessels often had a distinctive chemical make-up, containing high levels of lead. The same composition of white glass has been identified in the decoration on unusual beads from mid-first century AD site at Stanway and slightly earlier from Glastonbury Lake Village, as well as an in LIA glass bangles from Wales (Henderson and Warren, 1981; Paynter et al., 2022; Paynter, 2007) made in Britain. These objects were probably made from carefully recycled polychrome vessels, retaining the definition of the white so that it could be used for decorative elements on new objects. An example from Traprain Law in Scotland similarly displays recycling of a purple and white marbled vessel for bangle production (Stevenson, 1956).

When recycling a polychrome object that is dominated by a very strong stable colour, like cobalt dark blue with decoration in other colours, the object could be re-melted in entirety, stirring in any coloured trails, and the dominant overall colour would be retained (see the experimental section below for an example of a cobalt blue object with coloured decoration). Whereas if a neutral (colourless or naturally-coloured) glass object with coloured decoration, like a colourless glass bangle with a blue and white cord, is recycled then traces of the colour of the decorative element are likely to remain, albeit weakened; This example would result in a pale, weakly opacified grey /

blue. Evidence of this mixing process, manipulating polychrome glass when it was hot, can be found in the form of the relics of opacifiers in the glass microstructure (Paynter et al., 2022). Although opaque glass is heterogeneous in nature, the presence of indistinct trails in a contrasting colour may indicate the recycling of a polychrome object. Streaks of opacifying crystals which would originally have been white, red, or yellow, can be seen in the bodies of glass bangles or beads (mostly blue), which are suggestive of recycling discarded or waster beads or bangles using a process which would allow the glass to be re-melted and shaped but not become fully homogenised (Figure 2). Similar patterns are seen with the introduction of cobalt blue to naturally coloured glasses where streaks of cobalt blue are still evident in the final product. This is often the case with cobalt blue coloured glass, because this colourant is stable regardless of the extent or duration of heating (Figure 2).

Extending coloured glass

Within the Roman world, glass production was a fairly well tuned art, where particular compositions of glasses were chosen for particular uses and functionality in manufacture, but there is evidence to indicate that indigenous glassworkers in Britain employed a much broader range of materials and methods to extend their glass supplies. Recent analysis of glass artefacts suggests that manufacturing processes were also different depending on the extent of Roman influence, and certainly did not follow the strictly standardised practices which appears to be typical of Roman glass working (Paynter et al., 2022).

When particular effects or colours were desired, yet there was insufficient glass, some glassworkers in Britain resorted to novel, skilled techniques for extending the glass whilst still retaining the desired colour and opacity. These techniques have been observed in bangles in the north of England and southern Scotland from around the mid-first to early second centuries AD, attesting to a mismatch between the demand for, and supply of, coloured glass in those areas at the time. The yellow and white glass used to make monochrome Type 3 bangles have a diluted composition (Henderson, 1992; Newton, 1971; Paynter et al., 2022) made by mixing opaque yellow or white glass with naturally-coloured / colourless transparent glass, suggesting there may have been insufficient opaque glass. The effect was still a yellow or white colour, but slightly muted or dulled in intensity (Figure 3). These glasses also attest to the ability of glassmakers to achieve particular tonal effects without spoiling the glass.

The second method used for extending coloured glass was to make composite objects. For example, Type 1 bangles found in Scotland appear to have been produced by overlaying bands of strongly coloured glass onto pre-formed neutral translucent blue green bangles (Ivleva, 2020; Stevenson, 1956, 1976). These bangles are typically found at Traprain Law where it has been suggested they were made (Figure 4), but also at British sites such as Newstead (Hoffmann, 2003). This sheath of glass would reduce the amount of coloured glass and potentially heat needed to produce a bangle and be more economical. These bangles demonstrate another resourceful method of extending supplies of coloured opaque glass at a time when colourless and naturally-coloured glass was starting to dominate. It also typifies the adoption of what Hoffmann calls a ‘concept’ by producing bangles in a way more akin to traditions and colours in the north, and specifically Scotland (2003, 44). The production method, which involves applying heat-softened layers of coloured glass in mainly red and yellow, has some similarities with Late Iron Age glass inlay techniques on metal objects (Davis, 2015) with the exception that inlays on LIA copper alloy objects typically used ‘sealing wax red’ glass with a lead oxide content of 30/40wt%, whereas the red glass on the bangles has a lead oxide content of around 10wt%, comparable with Romano-British red glass.

Guido (1978, 51) class 5 beads show a variation on this method, with colourless or naturally coloured glass surrounding a thin application of an opaque coloured glass, often yellow, around the inside of the perforation. Bertini et al. (2011) studied Class 13 and 14 beads made in the northeast of Scotland, which feature strongly coloured glass bodies with opaque coloured trails. When inspected closely with transmitted light, many beads were found to be made of different recycled glass colours, but because the beads were made with very dark glass, this effectively obscured the colour variation and they appeared to be a single colour.

Substitute colourants

Many of the minerals needed to make a naturally coloured glass strongly coloured or opaque are not readily available in Britain (for example cobalt and antimony) and would not have been available to the majority of glassworkers. So glassworkers wishing to make their own coloured glass, or modify and extend what they already had, would have to find alternative methods making use of more common materials. Some rare examples of these modifications have been identified amongst glass bangles from the 1st century AD, where hammerscale, a by-product of iron smithing, has been added to cobalt blue glass. Similarly, examples have been found where plant ashes may have been added to colourless glass to produce bubbles and calcium silicate crystals that make the glass appear opaque white (Paynter et al., 2022) (see below). These examples of altering glass during recycling also use recycled waste products from other high temperature processes; they are unusual modifications that are not found in typical Roman glasses.

EXPERIMENTAL DEMONSTRATIONS

Recycling of polychrome glass

Many of the observations reported in the previous discussion, of mixing, extending glass and the variable effects seen in the finished product are derived from observations during visual examination of the artefacts themselves (see ‘Recycling and reusing glass’) but sometimes the mixing is so complete that it can only be picked up by chemical analysis. This can be demonstrated by experiment, in this instance a dark blue core-formed vessel (coloured by cobalt and copper oxides) with decorative trails in yellow (coloured by lead antimonate) and turquoise blue (coloured by copper oxide and calcium antimonate) made by glassmakers David Hill and Mark Taylor. The vessel was broken into fragments and the pieces with the largest volume of cobalt blue glass, which were the rim, the handles and upper part of the body (these had trails of yellow but no turquoise), were coarsely crushed to mix the colours. This mixture was heated in a crucible at 1100^{o}C for 2 hours in a neutral atmosphere and the resulting homogenous dark blue, transparent glass is shown in Figure 5 (bottom right). After firing, the lead antimonate trails had dissolved but the dominant dark blue glass colour appeared unchanged (Figure 6). The composition of the recycled glass was virtually identical to that of the blue glass used for the body of the original vessel except for a minor amount of lead oxide, a remnant from the melted-in yellow trails but the antimony in the recycled glass was below detection (0.3wt%) using SEM-EDS analysis.

Creating white glass

Evidence has also been found that some glassworkers in Britain were making opaque white glass from colourless glass by adding something to it that caused lots of crystals and bubbles to form (see 'Substitute colourants' and Paynter et al., 2022). These small crystals and bubbles acted as extra opacifiers in the glass but were only effective if they were evenly scattered and very small. Several attempts were made to recreate the microstructure of these modified white glasses, by stirring or folding plant ashes or calcium carbonate into hot soda-lime-silica glass. The molten glass failed to wet the added powder however and left large unreacted clumps in the glass (Figure 7). It was very difficult to evenly dissipate the additive through the glass by further hotworking and manipulation; more so whilst trying to avoid dissolving the small particles and bubbles needed for the opacifying effect.

Instead a fritting method was probably used, which may have involved coarsely crushing transparent colourless glass cullet and mixing it with plant ashes or another source of calcium carbonate. This combination of ashes and crushed colourless glass was then probably underfired so that the glass and additives are well mixed but with heating kept to a minimum, to retain the opacifying particles and bubbles. An experiment heating a soda lime silica glass batch containing 7wt% of calcium oxide overall to 850-900^{o}C recreated a similar microstructure with bubbles, small wollastonite (calcium silicate) crystals (and some undissolved quartz in this case) (Figure 8). The underfiring is essential because as the melt increases in temperature, the glass becomes less viscous which would eventually allow the bubbles to coalesce and escape. The bubbles are potentially more effective opacifiers than the wollastonite crystals because the refractive index of the crystals is quite similar to that of the glass matrix, whereas the refractive index for air is much lower (Kingery et al., 1976).

COMMENTS

Recycling and supplies

As demonstrated here, recycling in strongly coloured glasses is harder to identify using only glass compositions relative to unadulterated glasses, and so it's necessary to use both chemical analyses to identify slight differences in composition, in conjunction with visible and high magnification imaging to observe technological changes and the innovative use of materials. Experimental work also enhances our understanding of the process when led by analytical work or observational data. The large database of known compositions has informed this analysis, as it is now understood that different glasses in this period were made in a variety of locations, that those locations can be geographically pinpointed and that these glassmaking centres used the same raw materials from the same general regions for their lifetime – thus producing a stable and predictable glass composition. Most importantly, these compositions have a particular life span, which allows an understanding of what glasses were available at particular periods and when they went out of use, and so can be identified in the recycling chain.

Trading links, particularly in Britain, influence what is available and what can be reused and these affect the supply of glass, which would ultimately be over long distances, particularly for raw glass produced in the eastern Mediterranean. Similarly, most colourants or sources of coloured glass, including cullet, would have originated from outside Britain, some from exotic locations. In Britain, it seems that the southern and north eastern sites had the most direct access to cullet and possibly raw glasses. There also appear to be distinctive trade routes observed for the movement of particular glasses, with different supply mechanisms in different locations, some using sea routes as well as land trade. This is clear from the different regional patterns of glass supply and use (Foulds, 2014).

The compositional data in particular have shown that glassworkers using coloured glass in the transitional period at the end of the Iron Age and the beginning of the Roman period in Britain were adapting and modifying their glass by adding extra materials as colourants and mixing and extending the glass. These techniques may be associated with particular groups of people, but they are not typical Roman practice. The availability of glass for working and recycling may have been influenced by the movements of the Roman army who were relatively mobile in this period, but it is clear whatever internal trade was taking place, supplies of coloured glasses to the various parts of Britain were significantly different. It appears to be particularly in the north and northeast that the glassworkers continued to be innovative in their reuse and adaptation of glass to produce the desired commodity in their own cultural milieu, demonstrating a variant cultural determination relative to Romano-British glassworking in central and southern Britain, where standardised practices had long since been adopted. The availability of 'fresh glass' was not a significant limiting factor – the glass workers were able and willing to use whatever was available and used this with some imagination, utilising a variety of different methodologies.

Style, regionality and craftwork

It has been well attested that different regions produced glass ornaments with a distinctive geographical and regional style, and during working, glass was also manipulated differently. This may have been because of the supply mechanisms allowing some workers access to a greater diversity of glass colours, but also about knowledge of glass and how it may be cleverly used. In some regions and periods strongly coloured glasses were harder to find, and some opaque colours were probably reshaped or re-melted only infrequently as they are less likely to retain their colour. This limited supply of coloured glass meant that the glassmaker used more involved, innovative or complex methods such as wrapping opaque or highly coloured glass around naturally coloured cores for bead or bangle production, as opposed to the full, mass remelting of transparent glass practiced in the later Romano-British period when transparent glass was ubiquitous and common. The range of goods manufactured however was much more limited in terms of bangles, beads, inlays and enamels in Britain and this may have been also influenced by skills of the glassworker, glass availability or simply demand. These methods of glass manipulation demanded skill and an understanding of glass, even if glassworkers did not have the capability in terms of skills or materials to manufacture glass.

Significance of colour

This paper gives examples of some of the innovative ways used to exploit, extend and reuse glass in the Late Iron Age and Roman periods in Britain, and it is clear that coloured glass was in high demand for items of personal adornment. The use of glass and hence glass beads has often been linked to ideas of the exotic and so high status (Henderson 1991b, 107) because glass was relatively rare in these societies, however the significance of coloured glass and gemstones, in the past as now, is often more profound than this. By virtue of their glossy vivid colours, these materials are often considered to be imbued with particular properties, for example healing, or associated with specific customs or symbolism (Guido, 1978, 22). Giles (2008, 72) suggests strongly coloured glass items, in particular beads, may be linked to attributes of identity such as age and gender (Giles, 2008, 72) although Foulds (2014, 408) analysis presents an alternative or potentially complimentary hypothesis, that they represent a regional identity rather than status – a symbolism suggesting local or others, and only worn by some, as she and others have found clear regional patterns visible in the use of colour and decoration (Foulds, 2014, 401; Stevenson, 1956; Price, 1988). This regionalism may also further reflect the limited exchange of materials (Foulds 2014, 404), although it is clear from the analysis presented here and by Paynter et al. (2022) that there was significant movement of some raw materials, whether in the form of raw glass or material available for re-melting and reshaping, if not the items themselves; and also that glass, even if it was in short supply, was innovatively used and reused to produce striking and colourful items which attest not only to a demand but to an extremely skilled and knowledgeable workforce adept at manipulating glass.

In conclusion, it is clear from this survey that some of the earliest glassworkers in Britain had the skills, knowledge and expertise to manipulate a highly complex material and produced novel new ways of extending glass and creating vivid colours and effects in the glass. These colourful bangles fuse an existing local taste for highly coloured jewellery with Roman materials, and represent a distinctive local tradition that emerged in world which was influenced by Roman rule. The distinctiveness of the technology, found at the edges of the province may have been used to express identities, debatably in opposition to Rome. However, their reasons for producing these unique items and the novel technologies used to produce them may have also been many and complex, relating to status, kinship or customs. Looking at the technology of bead and bangle production and composition of the glass, stylistic attributes and distribution patterns of glass objects, along with population distribution and movements, gives us a more nuanced picture of the use of glass and the complex network of recycling of this material in Britain in the late Iron Age and early Roman period.

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FIGURE CAPTIONS

Figure 1: One of several fragments of transparent blue vessel glass, found with a collection of tesserae and coloured glass cakes at West Clacton, which had been repurposed as tesserae (Paynter et al. 2015)

Figure 2: Streaky, incompletely mixed coloured glass in Romano-British bangle fragments from Thearne, RF216 (L) and RF355 (R), showing probable recycling by hot manipulation of glass

Figure 3: A fragment of a glass bangle from Arbeia (T1585), which has been made from diluted, modified white glass.

Figure 4: A Type 1 bangle GV1017 from Traprain Law

Figure 5: The core formed polychrome vessel (top 3 images), showing the pieces selected for recycling (top right), which were crushed coarsely (bottom left), the melted to form a homogenous transparent blue glass (right)

Figure 6: SEM BSE images of the glass before recycling (left) with (top) lead-rich yellow glass trails (white in image) and the cobalt blue body (grey in image), and (bottom) at higher magnification the opacifying yellow lead antimonate particles (white in image) and (right) the homogenised transparent glass after recycling.

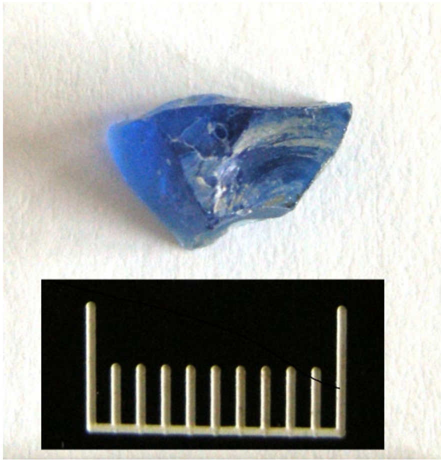
Figure 7: Plant ashes hot folded into natron composition glass (left) and back-scattered SEM image showing a rod cross-section, illustrating the uneven distribution and limited reaction of the ashes added in this way.

Figure 8: Calcium-rich wollastonite crystals and small bubbles (and some undissolved quartz grains) dispersed in a soda-lime-silica experimental glass, underfired to 870°C.

TABLE CAPTIONS

Table 1: SEM-EDS analysis of polychrome vessel, the discreet blue body and yellow trails before recycling, and the homogenised mixture of the two after recycling (normalised, bd = below detection limit).

FIGURES AND TABLES



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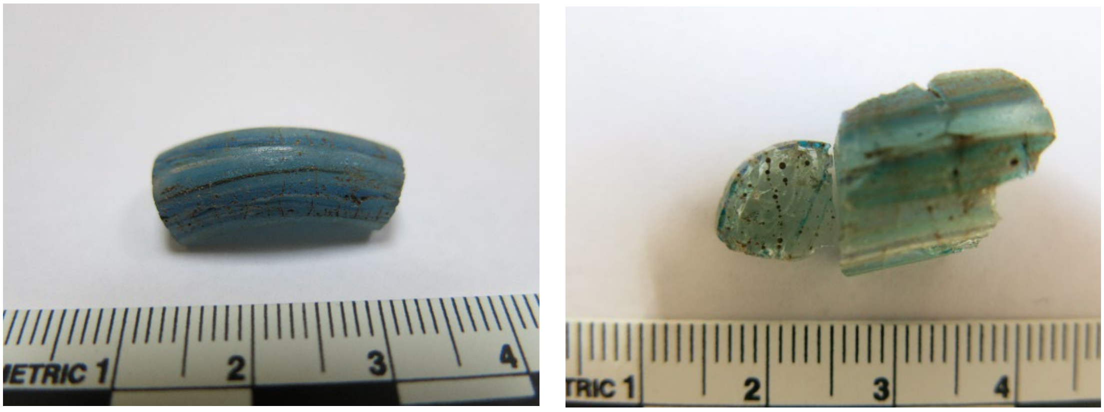

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Figure 3: A fragment of a glass bangle from Arbeia (T1584), which has been made from yellow glass opacified by lead antimonate crystals (white specks) diluted with colourless glass and modified with calcium silicate crystals (mid-grey specks) and bubbles (grey and black voids) as shown in the BSE image on the right.

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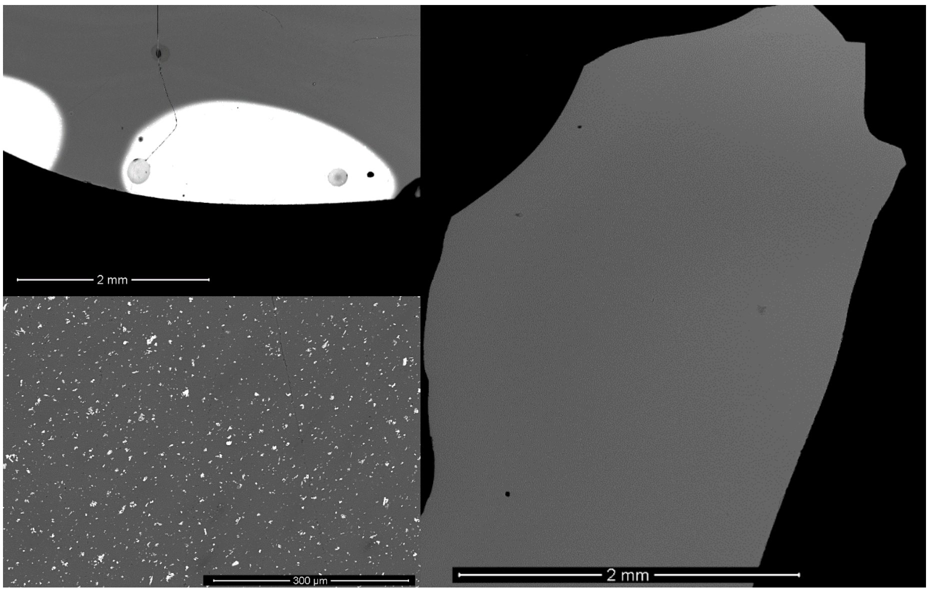

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Table 1: SEM-EDS analysis of polychrome vessel, the discreet blue body and yellow trails before recycling, and the homogenised mixture of the two after recycling (normalised, bd = below detection limit).

	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	CoO	CuO	SnO_2	Sb_2O_5	PbO
Opaque yellow	11.62	0.67	2.27	56.60	0.62	7.91	bd	bd	bd	bd	bd	bd	2.24	17.82
Opaque yellow	11.80	0.64	2.33	56.66	0.64	7.97	bd	bd	bd	bd	bd	bd	1.99	17.84
Opaque yellow	11.59	0.68	2.25	56.73	0.60	7.84	bd	bd	bd	bd	bd	bd	2.13	18.00
Opacifier particle	2.80	0.43	0.23	8.88	0.16	4.57	bd	bd	bd	bd	bd	0.59	47.66	34.48
Dark blue	15.72	2.72	1.26	67.54	2.22	7.42	0.07	0.32	0.51	0.09	1.70	bd	bd	0.09
Dark blue	15.59	2.68	1.24	67.56	2.22	7.47	bd	0.32	0.51	0.10	1.97	bd	bd	0.09
Dark blue	15.52	2.63	1.28	67.49	2.18	7.44	bd	0.36	0.46	0.05	2.12	bd	bd	0.09
Recycled	15.43	2.57	1.25	67.15	2.21	7.40	0.08	0.33	0.55	0.14	2.11	bd	bd	0.47
Recycled	15.31	2.62	1.32	67.12	2.29	7.49	0.08	0.28	0.47	0.10	2.10	bd	bd	0.39
Recycled	14.93	2.55	1.24	66.57	2.31	7.56	0.06	0.24	0.50	0.12	2.07	bd	bd	1.55

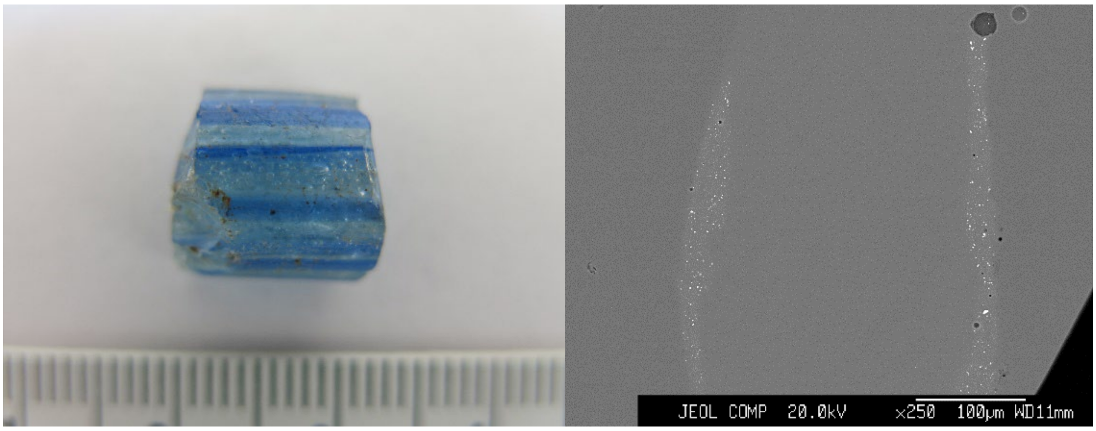
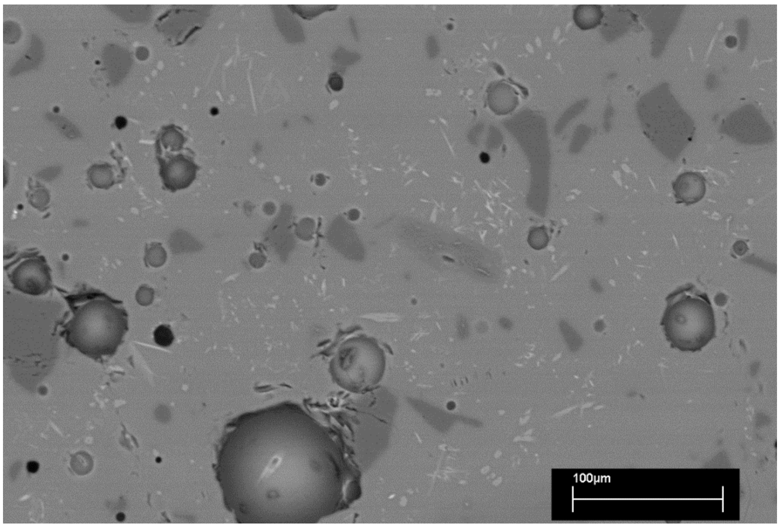


Figure 7: A Romano-British bangle fragment (RF355) from the site at Thearne, with incomplete mixing or cobalt blue, white and colourless glass, and trails of opacifying particles still visible in the microstructure.

Figure 8: Plant ashes hot folded into natron composition glass (left) and back-scattered SEM image showing a rod cross-section, illustrating the uneven distribution and limited reaction of the ashes added in this way.



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