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COMPOSITIONAL AND STRUCTURAL ANALYSIS OF THE GLASS BEADS FROM BOSS HALL AND BUTTERMARKET (ST STEPHEN'S LANE) EARLY ANGLO-SAXON CEMETERIES, IPSWICH, SUFFOLK

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Summary

A range of bead forms from these sixth- and seventh-century burials was investigated. Most of the beads were monochrome, but two examples had reticella decoration and there were several other beads with trails and spots. Manufacturing techniques also varied, including wound and 'pushed through' examples. An X-ray fluorescence (XRF) survey of the monochrome beads indicated that seventeen cobalt-blue drawn cylinder beads from four graves at Boss Hall were very close compositionally but a typologically-similar example from Buttermarket was quite different. Three of the translucent green beads were coloured by high copper and lead contents, but iron was the colourant in other cases. Tin compounds or tin and antimony compounds were the opacifiers in opaque green beads. Energy-dispersive X-ray analysis (EDX) of small samples confirmed that the glasses were soda-lime-silica glass and gave the patternings indicated by XRF a degree of quantification. The copper-lead translucent green glasses were compared with examples from other sites. The same samples were examined for inclusions. These included areas of iron crust, where iron tools were used to shape the bead. In the case of one of the copper-lead translucent green glasses, contacts with these areas had caused streaks of copper-rich inclusions.

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Compositional and structural analysis of the glass beads from Boss Hall and Buttermarket (St Stephen's Lane) early Anglo-Saxon cemeteries, Ipswich, Suffolk

Catherine Mortimer and Tim Horsley

Examination and analysis was carried out on the glass beads in order to identify the colours accurately, to suggest methods of manufacture, to identify the source of colouration and to identify other technological features. It was of particular interest to determine whether beads with similar appearances, but found in different graves, had similar compositions and manufacture. For example, drawn cylinder beads were found in several graves, as were annular translucent blue/green beads and opaque green beads. The compositions of the Ipswich beads can also be compared with the results of quantitative analyses of other early Anglo-Saxon beads (Mortimer 1996a, 1996b; Henderson 1990).

Methods of analysis

Visual. All the beads were examined using a low-powered microscope (at x10 and x30) and a strong light source. In most cases, this was sufficient to allow the true colours of the glasses to be established. Where thick irridescence or severe abrasion obscured the glass, a small amount of industrial methylated spirits was applied and this temporarily gave a clearer idea of the colour. Notes were taken of any evidence for the method of manufacture, together with any tool marks, inclusions and abrasion seen (see Catalogue). Boss Hall is abbreviated here as BH and Buttermarket (St Stephen's Lane) as SSL. Some of the Boss Hall beads have British Museum numbers (BM), rather than small finds numbers (Δ).

X-ray fluorescence. Most of the beads were analysed using surface X-ray fluorescence (XRF) analysis, for two reasons. XRF allows most colourants and opacifiers in glass to be identified. For example, many Anglo-Saxon glass beads are coloured by copper, in a reduced state in opaque red glasses and in an oxidised state in some green or blue glasses, and copper can be easily detected by XRF. At the same time, XRF can also be used to record information about some of the important major and minor elements found in glass, *eg* calcium, manganese and iron. Hence an XRF survey can be carried out to determine whether a number of beads from different graves which have very similar appearances are compositionally similar.

Surface XRF is non-destructive and quick, but it has a number of drawbacks. The data recovered relates to the composition of the top layers of glass, which are likely to be corroded and contaminated due to burial. This means that significant compositional variation may be recorded within a single artefact or between two artefacts with similar compositions; iron, manganese and calcium are elements of particular concern with respect to contamination. It is safe to assume that two beads with the same composition, subject to

similar deposition conditions might have comparable corrosion patterns.

The ideal XRF sample is flat, polished and homogeneous. Evidently none of the beads conform to this requirement, and hence additional errors will be introduced.

Analysis is usually only qualitative or semi-quantitative, that is, determining either the absence/presence of elements or the intensity (represented by the peak area) of the X-ray peaks which relate to each element, rather than oxide or element percentages. Each element has a different response to the X-ray beam, so that a peak height or area does not directly relate to the amount of that element present. For example lead, being a heavy element, produces copious amounts of X-rays, and is therefore easy to detect, even at low levels. On the other hand, calcium is usually present in significant quantities in Anglo-Saxon glasses, but has a small response to XRF because it is a relatively light element. The very high peak area values recorded for lead should not therefore be taken to mean that the glass contains huge amounts of lead.

The iron Kα peak was used despite a considerable overlap with the manganese Kβ peak. This overlap means that the area calculated for iron Kα also includes a contribution from manganese equivalent to about one sixth of the peak area of manganese Kα. Detection of cobalt also suffers badly from an overlap with iron. In an effort to improve this, all the beads were analysed with the equipment set up with a smaller number of eV per channel than normal (20eV per channel). This gave a slightly clearer impression of the shape of the peak, and the cobalt Kα peak could be sought, in the form of a slight shoulder on the side of the iron Kβ peak, but did not allow the analysis of higher energy (>20kV) X-rays. Subsequently all beads in which tin was thought to be present were re-analysed at 40eV per channel, allowing the tin K peaks to be examined.

The zinc Kβ peaks were used because the zinc Kα peaks overlap with the copper Kβ peaks, thus the zinc peak area values are relatively small.

Without reference to analyses from suitable standard glasses, it is difficult to quantify XRF data in such a way that they can be compared with quantitative analyses, but it is possible to collect data which can be compared with other XRF data. In addition, analyses of the same samples can be carried out using SEM-EDX, thus allowing some approximate calibration.

Polychrome beads were omitted from analysis as it was difficult to avoid analysing more than one colour but analysis was carried out on all the monochrome beads. In each case, the beads were analysed for 100s (live time), running the X-ray tube at 35kV and 400μA and using a 1mm collimator. Orientation of the sample was also determined to be an important factor, and where the beads had a long axis (*eg* the drawn cylinders), they were aligned with the plane of the X-ray beam. Peak areas were recorded for calcium, manganese, iron, copper and lead, and the absence/presence of antimony, cobalt, nickel, arsenic, gold, silver and tin was noted. No attempt was made to record information for sodium, magnesium, aluminium, silicon and phosphorous. Although they are of interest in the study of glasses, their X-rays are easily absorbed in air - even under a vacuum, the peak areas are still very small. The results of XRF analysis are given in Tables 1 to 3 and Figures 1 to 5.

Scanning electron microscopy and energy dispersive X-ray analysis. Small samples were taken from ten beads and from one of the palm cups. These were prepared for examination and analysis in the scanning electron microscope, using energy-dispersive X-ray analysis (SEM-EDX). The excellent preservation of many of the beads meant that it was not possible to sample without risking significant damage. The analytical results are presented in Table 5 (for further detail of the method, see Mortimer 1996a).

Analysis of two standard glasses (Table 6) suggests that the method is reasonably accurate, with some exceptions. Soda levels are rather too low and the detection of cobalt is slightly poorer than by XRF. Also, because a restricted range of X-rays (0-20keV) are normally detected, this does not allow the examination of the tin and antimony K peaks which lie above 20keV, forcing reliance on the L peaks, which are overlain by potassium and calcium peaks. This makes accurate quantification and detection of small amounts of these elements difficult, so a visual check was carried out on this area of every spectrum, allowing absence/presence of tin and antimony to be noted. Further work on calibration is required to improve on this less than satisfactory situation, and time restrictions did not permit this.

Sections taken from beads also allow investigation of microstructure, particularly concentrating on homogeneity and on the nature of individual inclusions. A combination of EDX and back-scattered electron (BSE) imaging is particularly useful. In BSE, those areas containing elements or compounds with high atomic numbers are brighter than those with low atomic numbers. For instance, lead-rich glasses are brighter than normal soda glasses. The results of a study using EDX and BSE imaging are summarized in Table 7.

Results

Colours and forms. The translucent beads can be divided into three main groups; drawn cylinders of green or blue (19 examples), colourless/pale green segmented (or 'beaded') cylinders (11) and green or blue beads of forms which can be described as annular, disc or short cylinders (10). Some of the latter type have a slightly golden or silvery iridescence on the surface. The only exceptions to this were two translucent melon beads, a blue one from BH93 (Δ1) and a green one from SSL3362 (Δ18) and two dark green beads from BH313 (Δ52 and Δ54) which seem to be coiled cylinders. There were also three fragments of blue beads from BH32.

Of the nine monochrome opaque beads, there are seven opaque green beads, which are of disc or short cylinder types, except for one (BH 94 Δ17) which is a 'melon' type. The bead from BH32 Δ12 is also opaque, but its colour is more like turquoise than green. A bead from SSL4222 (Δ25) may have been intended to be simply opaque red but has black spots on its surface (see discussion below).

Polychrome beads feature several different colours and designs. Two polychrome beads are of pale translucent green or near-colourless glass with reticella decoration on them. Reticella is created by placing together strips of two or more glasses of contrasting colours and then heating, twisting, marvering (rolling on a flat, hard surface) and stretching so as to form a single cylinder or rod with a small radius. This rod is then used as a 'trail' and marvered into the surface of the beads. As one of the colours in the reticella rod was often colourless or lightly-tinted, this would be invisible to the naked eye, so a zigzag of the contrasting colour would be seen. The reticella on the example from BH93 comprises a twist of opaque yellow with translucent green glass (hence seems to be a zigzag of opaque yellow). The example from SSL3362 has two different twists, one of opaque white with translucent pale green and the other with opaque yellow with translucent pale green. An opaque red bead from BH94 (Δ46) is decorated with a reticella rod of opaque yellow and opaque green.

Other polychrome beads with translucent base colours include two with opaque white trails; a translucent amber/brown bead (BH35 Δ49) and a translucent green bead from BH151 (Δ47). A translucent blue bead from BH35 (Δ9) has opaque red dots on it.

Two opaque red beads from BH32 (Δ5 and 6) have translucent blue and opaque white glass decoration. Similarly, an opaque red bead from BH94 (Δ44) has opaque yellow/white

and pale translucent blue glass trails. An opaque green bead from BH94 (Δ45) has opaque red trails on it.

In addition, two rock crystal beads, four jet beads and one amber bead were found at the sites. These are not considered here.

Manufacture. All of the drawn cylinders appeared to have been produced in a very similar way, one which had resulted in heavy striations on the outside. In some cases, it was clear the beads had been formed by lengths being cut or nipped off from longer canes. The segmented beads were presumably made in a similar manner, although some of them also include layers of gold or silver foil to give a gilded effect (Bayley 1994).

The annular and disc beads show more variety in manufacture. Some showed evidence of having been made by coiling glass around a core or rod (*eg* BH32 Δ3, SSL4222 Δ26 and SSL4275 Δ24), leaving the remains of a 'swiss roll' effect. Others were clearly made by pushing a rod through a blob of molten glass, notably SSL1674 Δ30-32, three beads which all seem to have a wood grain impression on one side.

Some beads were noticeably better made, especially the two reticella beads with translucent base glasses (from BH93 and SSL3362), but also an amber/brown bead (BH93 Δ49) and one of the pale translucent green annular beads (BH94 Δ43). These beads have a distinctive 'doughnut' shape. The glossy appearance of some of them may be due to 'fire polish' (*ie* reheating the bead after it had been shaped, in order to remove roughness caused during working). When viewed in transmitted light, streams of bubbles, many of them very small, could be seen spiralling out from the centre of BH93 Δ49. These may have been created by the reaction between the glass and the iron rod around which the glass was coiled. There are indications that the same may be true for BH93 BM20 and BH94 Δ43.

Tool marks can be seen on the surface of an opaque green bead (BH93 BM23), where pincer- or tweezer-like tools were used to form it or to pick it up whilst the glass was still soft. Similar tools may have been used where beads are fluted (*eg* BH32 Δ12) and on melon beads. A flatter, wider tool would have been used where beads are flattened on the top and bottom faces. A clear break can be seen at the end of the piercing, where the melon bead from BH93 (Δ1) was removed from the rod.

Black spots or streaks were noted on or in nearly all the opaque red glass, whether used as a base glass or in decoration (BH32 Δ5 and Δ6, BH94 Δ44, Δ45 and Δ46, and SSL4222 Δ25). This feature has been noted in earlier studies and, at Barrington (Cambridgeshire), one such particle was shown to be iron-rich, possibly a piece of ironworking slag (Mortimer 1996b, 5). These inclusions may be flakes from iron tools used to stir the glass. In some cases the particles seem to have adhered to the outside surface of the bead, so they may have been picked up during marvering on a dirty surface. In either case, it is difficult to explain why they are not as frequently seen amongst other colours of glass. Another possibility might be that an iron-rich compound may have been deliberately added to the opaque red melt - raising the iron content enhances the colour - but that the glass was not adequately heated after this addition to allow homogenisation. An opaque red glass sample from Mucking (Essex) was found to have fragments of probable ironworking slag within it (Mortimer 1996a, 7).

At Boss Hall, an opaque green glass (BH32 Δ4) also has a large black 'flake-like' inclusion and the opaque green green glass used in BH94 Δ45 has both dark brown and white inclusions.

None of these inclusions were analysed in this project, although whole beads can be examined in the SEM and submitted to qualitative EDX (*cf* Mortimer 1996b, 5).

Preservation. Some of the beads are poorly preserved. This may be due to aggressive burial circumstances and certain bead or glass types seem to suffer more than others; the segmented cylinders are often very fragile. In the case of some of the well-made, well-preserved examples, it can be seen that they still have good glossy surfaces in most areas, but that the 'facing' surfaces (*ie* those which touched the next bead in the string) are abraded. Irridescence was noted in several cases, including one of the reticella beads (SSL3362 Δ17) as well as several others from both sites.

XRF analysis. The XRF data will be considered primarily by glass colour, but also by form.

The data gathered for **translucent blue beads** demonstrate several features which are also true for other glass colours. Table 1 and Figure 1 show the raw data. They illustrate the diversity in total peak areas, ranging from less than 5000 counts to over 90000; this relates to the size of the object - the fragments have the smallest total peak areas. Normalising the data makes it easier to compare information from different samples (Figure 2), but it should be remembered that data from fragments have relatively large errors associated with them, as the absolute numbers are so much smaller. In Figure 2, the samples are ranked in order of increasing normalised lead peak area, showing that in some of the samples nearly 50% of the total peak area recorded was from lead. It should be stressed again that several important glassforming elements were not or could not be recorded using the methodology employed here and that the sizes of the X-ray peaks are not directly proportional to the percentage of the elements or oxides present. Most of the analyses produced very small zinc peaks.

Beads with similar compositions should show similar patterns of peak areas, even when the problems associated with analysis (pages 1-2) are taken into account. Cobalt is present in all of the blue beads and this is a strong colourant; copper is also present in each case, and may have added to the final colour. The relative amounts of the other recorded elements vary, but show some strong patterns. The first three samples on the left of Figure 2 seem to have very similar patterns, each with a dominant iron peak and only small lead peaks. These samples are annular or disc beads; BH32 Δ3, BH94 Δ29 and Δ42. Similarly, the seventeen samples plotted on the right of the figure are very comparable to each other, with strong lead peaks, slightly smaller iron peaks (compared with the first group) and a calcium:manganese ratio of about 1:2. These are the drawn cylinder beads, chiefly from Boss Hall grave 94, but also three from graves 32, 97 and 313. The drawn cylinder bead from Buttermarket 4275 Δ24 (not plotted on Figures 1 and 2) however has a very different composition, with no manganese detected and very high copper levels. This sample was also unusual in that tin was detected. Of the remaining four samples in Figure 2, three are fragments from Boss Hall grave 32 and one is a melon bead (BH93 Δ1). The composition of the melon bead is characterised by low manganese levels but otherwise could be considered broadly similar to the drawn cylinder compositional pattern. It is probably unwise to place much emphasis on the XRF data from the fragments, given the very small peak areas, but BH32 Δ8 and Δ13 seem to be compositionally slightly closer to the disc and annular beads than the drawn cylinder group. A further translucent blue bead (BH93 BM1) is held at Ipswich Museum and was not analysed for this project.

The **translucent green** beads comprise 11 segmented cylindrical beads from Boss Hall grave 94 and 10 other beads of a variety of forms. The raw data for the segmented cylindrical beads (Table 2) indicates much lower copper and lead contents than seen in the translucent blue drawn cylinder beads. Iron thus becomes the only dominant peak on a 'profile plot' (Figure 3). A very similar profile could be plotted for the translucent blue disc

and annular beads discussed above, except that the blue beads have a higher copper content. Within the general compositional pattern for the translucent green segmented beads, sub-groupings could be suggested *eg* on the basis of iron:manganese peak ratios, as indicated by the use of three different types of line in the plot. These patterns could originate from the use of glasses from different sources but they may merely reflect different degrees of contamination from the soil. Traces of cobalt were detected in two cases, and possible traces in seven other cases.

BH94 Δ18 was the only segmented cylindrical bead which provided evidence for a gold layer within the glass - this could be seen both visually and analytically. The other segmented beads yielded no evidence for precious metal content. This may be for one of two reasons. Gold or silver may have been present but are not now detectable, due to corrosion and loss. Alternatively they may never have been present, with a similar visual effect being achieved by a combination of the colour of the glass and the effect of double layers of glass (Bayley 1994).

The other translucent green beads have a variety of compositions (Table 3 and Figure 4). The most noticeable composition type is one with a high copper and high lead content used to make three beads: BH32 Δ2, SSL3362 Δ18 and SSL4222 Δ2 (dashed lines on Figure 4). Lead enhances the green colouration produced by copper. The copper peak for these beads is even more sizeable than in the blue beads and tin is additionally detectable in each case. The beads are a drawn cylinder, a melon bead and annular/short cylinder bead. Two coiled beads from BH313 (Δ52 and Δ54) also have a composition which is easily distinguishable by its very high iron content; this has imparted a strong dark green colouration. The three 'pushed-through' beads from SSL1674 (Δ30, Δ31 and Δ32) are distinguished by containing detectable antimony; otherwise their compositions are not noteworthy and could, for instance, be compared with those of the segmented cylinders. Antimony has two possible functions in glass, one as a decolouriser and one as an opacifier, so it is presumably acting here as a decolouriser.

It is noticeable that the three translucent green beads which have high copper and lead contents also have detectable tin and elevated zinc levels. Zinc was also detected in six out of the nine opaque green glasses (see below), tin being the opacifier in these cases. The simplest explanation is that adding copper alloys rather than pure copper to the glass melt could have accidentally introduced both tin and zinc, but other mechanisms have also been proposed to account for some or all of the tin and zinc contents (Mortimer 1996b, 8). These include the presence of metal traces in glass-making materials and contamination with other glass types during working. As XRF is a surface technique, the possibility of contamination of the surface of the beads through burial contact with corroded copper alloy artefacts should be noted but it seems unlikely to provide a complete explanation, given the frequency of the observation.

High copper and lead contents are also a feature of most of the **opaque green** beads (Table 4 and Figure 5). Three beads (BH32 Δ10, BH94 Δ17 and SSL1674 Δ29) have high lead contents but moderate copper levels (dotted lines on Figure 5). These beads are also noticeable for having tin but no antimony detectable. BH32 Δ12 has high values for both lead and copper, as well as containing both tin and antimony, so it is broadly similar to the other opaque green beads, despite being rather more turquoise in colour. Also, there is little to distinguish this composition from the composition of a translucent green bead from the same grave, Δ2, except a rather larger lead peak. It is important to stress the present-day opacity of beads may be as much to do with vesicularity and preservation state as with composition. In addition, it is also interesting to note that antimony is never present without tin. Both may

be implicated in opacification, but antimony could have been present as a decolouriser in a translucent green glass (see *eg* the three beads from SSL1674) which was then opacified with tin-rich oxides. Four beads from BH93 have larger copper than lead peaks, BM2, BM4, BM21 and BM23 (solid lines on Figure 5). These are all short cylinders, although two of them have faceted (four- or five-sided) shapes, and appear visually similar in manufacture.

Conclusions. Some statements can be made on the likely colourants and opacifiers. All the translucent blue examples were probably coloured by a combination of cobalt and copper; although cobalt was only detected at low levels, it is a strong colourant. Green beads are probably coloured by copper in some cases and iron in others; where copper is the likely colourant, lead is normally present in significant amounts. The presence of cobalt in many of the green beads clearly was not sufficient to cause a blue colour. Tin-rich oxides were the opacifiers in some cases, but other beads may have had some opacity produced by antimony compounds.

On the basis of XRF, it is difficult to suggest exactly what sort of glass composition these analyses represent, although it is likely to be a soda-lime-silica glass; quantitative analysis using SEM-EDX (below) resolved this uncertainty. From the XRF data, it can be suggested that opacity was caused by the presence of crystals of tin and antimony compounds.

Using qualitative and semi-quantitative XRF analysis has given some patternings which are satisfactory in terms of grouping together, on a compositional basis, beads which are stylistically or technically similar, for example nearly all the translucent blue drawn cylinders or the three translucent green beads from SSL1674 which had been made in the same way. In addition, the single example of a translucent blue cylinder that deviated from the 'normal' composition for such beads came from Buttermarket (SSL4275 Δ24). This tends to confirm several archaeological prejudices, eg, that typologically-similar artefacts will have similar compositions. However, the reverse is not true. For example, three translucent green beads (BH32 Δ2, SSL3362 Δ18 and SSL4222 Δ2) with similar compositions are very different in form. In addition, there are some examples where beads with apparently similar compositions have different appearances, with the differences being explained by opacity due to bubbles or abrasion.

SEM-EDX analysis. As expected, all of the beads analysed proved to be soda-lime-silica glasses, with varied amounts of colourants and opacifiers, sometimes with the addition of lead (Table 5).

The sample taken from the palm cup from context 1306 (33/3104G) is a typical soda glass, with rather high calcium levels (10.2% CaO). No manganese was detected so decolourisation was probably due to the presence of small amounts of antimony, present below detection limits; the iron content is low so little decolourising would have been needed. This composition is comparable to those of other contemporary vessels, although manganese rather than antimony was normally detected (Sanderson *et al* 1984).

Two translucent blue samples were analysed, from BH32 Δ3 and BH35 Δ9. In the first case, cobalt was just detectable, as it was by XRF, but the colouration of the other may be due to the high levels of iron (2.3% Fe_2O_3) and manganese (1.4% MnO), rather than cobalt or copper. This bead was not analysed by XRF, as there are red spots on its surface. These compositions, apart from the elevated iron levels in BH35 Δ9, are closely comparable to those found in many other translucent Anglo-Saxon beads (*eg* Mortimer 1996a, 1996b; Henderson 1990).

Two translucent green glasses were analysed, BH32 Δ2 and SSL3362 Δ18. These both have significant copper and lead contents, and are otherwise quite comparable, despite the fact that they come from different sites and are different shapes. Although many translucent green glasses of early Anglo-Saxon date are coloured by traces of iron oxide, and are lead-free, a bead of the same compositional type was found at Mucking (Mortimer 1996a, sample 32). It is also likely, but difficult to prove, that some beads analysed in previous XRF surveys are also of this composition type *eg* some from Buckland (Bayley 1987, 185) and from Empingham (Heyworth 1996, 55). None of the beads from Barrington or Apple Down (Sussex) had this composition, although two beads from Barrington and one from Apple Down had elevated copper levels but low lead levels (Mortimer 1996b, samples 28 and 31; Henderson 1990, sample 26), the Apple Down example being an early example of mixed-alkali glass.

Five opaque green glasses were analysed and these are more varied compositionally. All except BH32 Δ4 have elevated copper levels - 0.5 to 4.5% CuO - which explains their colouration. BH32 Δ4 may be coloured by iron, although this is at quite a low concentration (0.6%). Two examples, BH93 BM4 and SSL1674 Δ29, have rather high potassium levels (1.1% and 2.3%).

Inclusions (Table 7). The samples examined included several with areas of iron 'crust' visible. These are where iron oxide 'scale' was pulled from the iron rod around which the glass was coiled (see also Mortimer 1996a) and are prevalent because the samples were often taken from inside the bead's hole. In a number of cases, the glass had reacted where it was in contact with the iron, producing a layer of bubbles. These reaction areas were subsequently vulnerable to corrosion attack and the iron crusts are often separated from the intact glass by a wide zone (50-100μ) of corroded glass.

Vesicularity is also quite common in areas away from the iron crust. In some cases, this can give a degree of opacity to the glass and it may explain why some opaque beads seem to have compositions which are similar or identical to those of translucent beads (*eg* BH32 Δ4).

Several other types of inclusions were also observed. Some are the inclusions which gave the glass its opacity (tin- and antimony-rich oxides), but there are some other inclusion types. Amongst the opaque green beads, opacity was due to several different factors; vesicularity (BH32 Δ4), antimony oxide inclusions (BH32 Δ12, probably with some tin oxide inclusions) and lead-tin oxide crystals (BH94 Δ17 and probably SSL1674 Δ29).

Some inclusions were noted amongst the glasses which were not judged opaque in the hand sample. SSL3362 Δ18 was particularly heterogeneous, with at least two areas of streaky, imperfectly mixed glass, one including a large copper oxide particle (*c.* 30μ long) and the other with particles which were high in tin and zinc, as well as containing iron, copper and oxygen. The particles also have a range of shapes - triangular, squareish and oval. The main body of the sample, away from these streaky areas, has very few inclusions. The streaks appear to be leading away from the iron crust contact area, so the iron may have effectively reduced the copper oxides to copper. As the bead itself was not noted to be opaque, it seems likely that this contact had a strictly limited effect; nonetheless it does seem to indicate one source of the streaky red glass seen frequently in other contexts.

Comparison between XRF and SEM-EDX. From this analysis it can be seen that XRF data sometimes overemphasises elements which are actually not major components of the glass, for example the 'high' iron content of BH32 Δ3 is actually less than 1% Fe_2O_3. However the

lead:copper ratio of the opaque green glasses provides interesting and roughly-comparable information using both XRF and the EDX data, so that future XRF surveys should be able to identify this type of glass with ease.

Conclusions

A combination of technical and compositional analysis has yielded useful information about glass beads from the early Anglo-Saxon period. A variety of manufacturing techniques is echoed by a variety of chemical compositions.

Acknowledgements

Tim Horsley carried out the XRF survey, whilst on placement at the AML. Malcolm Ward carried out some additional EDX analysis on the samples.

Note

The X-ray peaks used for peak area calculations and for noting absence and presence of elements are as follows:

Calcium	Ca Kα	Zinc	Zn Kβ
Manganese	Mn Kα	Lead	Pb Lα
Iron	Fe Kα	Antimony	Sb Lα
Cobalt	Co Kα	Tin	Sn Lα
Copper	Cu Kα		

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Table 1: XRF analysis of translucent blue beads

Sample	Peak Areas						Present			Shape
	Ca	Mn	Fe	Cu	Zn	Pb	Co	Sb	Sn	
Boss Hall										
G32 Δ3	5648	8302	23344	5346	0	3008	y	n	n	annular
G32 Δ7	5729	10938	27716	9130	271	44100	y	n	n	drawn
G32 Δ8	1932	268	6165	1802	0	1197	y	n	n	annular? frag.
G32 Δ13	601	10	1767	496	0	394	y	n	n	fragments
G32 Δ14	78	0	953	1392	96	943	?	n	n	fragments
G93 Δ1	3263	683	14340	2239	0	9177	y	n	n	melon
G94 Δ15	5332	11569	33438	7762	147	36758	y	n	n	drawn
G94 Δ20	6087	10967	28404	5508	0	35027	y	n	n	drawn
G94 Δ24	5114	10857	31706	6950	70	36734	y	n	n	drawn
G94 Δ28	5087	10838	23894	5121	91	30422	y	n	n	drawn
G94 Δ29	2945	2373	14201	2448	0	1928	y	n	n	annular frag.
G94 Δ31	4586	11286	26214	5791	132	26499	y	n	n	drawn
G94 Δ32	6029	11510	32463	11283	166	31024	y	n	n	drawn
G94 Δ33	6188	14175	30562	6804	13	32206	y	n	n	drawn
G94 Δ34	6043	14021	28213	6312	0	29426	y	n	n	drawn
G94 Δ35	4093	8875	22058	6365	0	28253	y	n	n	drawn
G94 Δ36	5809	11904	28033	6150	0	38250	y	n	n	drawn
G94 Δ37	5711	11115	27222	6410	0	30775	y	n	n	drawn
G94 Δ38	5884	11600	31480	8406	54	35515	y	n	n	drawn
G94 Δ39	5971	12216	32839	9163	223	37744	y	n	n	drawn
G94 Δ40	5712	11444	31242	8708	57	35746	y	n	n	drawn
G94 Δ42	4595	5507	23703	3676	0	2321	y	n	n	disc
G97 Δ48	5914	7791	22988	6897	205	26060	y	n	n	drawn
Buttermarket (St Stephen's Lane)										
G313 Δ53	6078	10150	26071	7178	173	39922	y	n	n	drawn
G4275 Δ24*	3371	0	9697	377398	1079	25088	y	n	y	drawn

* Omitted from Figures 1 and 2; y = detected, n = not detected, ? = possible trace detected

Table 2: XRF analysis of translucent green beads - segmented cylinders

Sample	Peak Area						Present				Shape
	Ca	Mn	Fe	Cu	Zn	Pb	Co	Au	Sb	Sn	
Boss Hall											
G94 Δ16	5343	10619	20162	754	0	0	?	n	n	n	segmented
G94 Δ19	3681	7032	10738	214	0	849	?	n	n	n	segmented
G94 Δ21	2335	5021	8897	173	0	734	?	n	n	n	segmented
G94 Δ22	5291	4498	15836	245	0	545	y	n	n	n	segmented
G94 Δ23	5809	10816	21797	431	0	2395	n	n	n	n	segmented
G94 Δ25	5260	9674	17172	933	80	857	?	n	n	n	segmented
G94 Δ26	7001	10145	22794	822	0	1528	n	n	n	n	segmented
G94 Δ27	1499	3547	6817	640	150	550	y	n	n	n	segmented
G94 Δ30	5624	9397	20944	643	0	493	?	n	n	n	segmented
G94 Δ41	4461	8221	16127	480	197	377	?	n	n	n	segmented
G94 Δ18	2217	9984	12301	199	100	375	?	y	n	n	segmented

Table 3: XRF analysis of translucent green beads (not segmented)

Sample	Peak Area						Present				Shape
	Ca	Mn	Fe	Cu	Zn	Pb	Co	Au	Sb	Sn	
Boss Hall											
G32 Δ2	3758	3037	8681	48753	2000	74337	n	n	y	y	drawn
G32 Δ11	6667	12539	17855	267	198	2284	n	n	n	n	drawn
G94 Δ43	6374	8656	7786	397	161	100	?	n	n	n	annular
G313 Δ52	3253	6982	63115	764	0	1445	?	n	n	n	coiled
G313 Δ54	1849	3098	44930	683	50	2988	?	n	n	n	coiled
Buttermarket (St Stephen's Lane)											
G1674 Δ30	1283	816	2329	325	190	165	?	n	y	n	disc
G1674 Δ31	3474	2226	5421	282	133	0	?	n	y	n	disc
G1674 Δ32	2453	1690	4517	341	30	94	?	n	y	n	disc
G3362 Δ18	2643	695	21667	52551	5000	59209	n	n	n	y	melon
G4222 Δ26	3942	252	9689	44438	4000	107544	?	n	n	y	rounded

Table 4: XRF analysis of opaque green beads

Sample	Peak Area						Present				Shape
	Ca	Mn	Fe	Cu	Zn	Pb	Co	Au	Sb	Sn	
Boss Hall											
G32 Δ4	4258	3517	5553	1008	0	9272	n	n	y	?	disc
G32 Δ10	1867	917	7373	17961	0	218949	n	n	n	y	4-sided
G32 Δ12	2853	3084	7725	69702	0	163020	?	n	y	y	5-sided
G93 BM2	4909	1211	16951	41415	1500	21436	?	n	y	y	rounded
G93 BM4	4433	1090	9530	27420	2000	8479	n	n	y	y	4-sided
G93 BM21	6045	1155	13738	36331	1384	21416	n	n	y	y	5-sided
G93 BM23	4687	930	13560	29874	1000	17150	?	n	y	y	rounded
G94 Δ17	7328	4175	10421	12816	1247	130495	?	n	n	y	melon
Buttermarket (St Stephen's Lane)											
G1674 Δ29	3721	587	14501	16207	3000	94212	?	n	n	y	disc

Table 5: EDX analysis of beads and palm cup fragment

grave/context, sf	colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	CoO	CuO	ZnO	SnO	Sb_2O_3	PbO	Total
Translucent glasses																			
G32 Δ3	blue	17.2	1.0	2.3	67.9	nd	0.6	6.4	0.4	nd	1.0	1.0	0.3	nd	nd	nd	nd	nd	98.0
G35 Δ9	blue	18.0	0.9	2.4	65.2	nd	0.6	6.9	0.2	nd	1.4	2.3	nd	tr	0.1	nd	nd	0.3	98.4
1306 27G (palm cup)	colourless	13.4	0.8	3.2	70.3	tr	0.4	10.2	0.1	nd	nd	0.5	nd	0.1	0.1	nd	nd	nd	99.3
3362 Δ18	green	14.3	1.2	1.8	61.2	0.1	1.0	6.7	0.3	nd	tr	0.8	nd	2.2	nd	nd	nd	3.6	93.2*
G32 Δ2	green	15.1	0.7	2.4	67.2	0.1	0.6	5.8	0.1	tr	0.5	0.5	nd	1.4	tr	nd	nd	3.1	97.7*
Opaque glasses																			
G32 Δ4	green	13.4	0.6	2.3	70.6	nd	0.6	6.9	0.1	nd	0.7	0.6	nd	tr	nd	tr?	nd	0.3	96.1*
G93 BM4	green	14.4	1.2	2.1	66.8	0.3	1.2	7.7	0.2	nd	0.3	0.8	nd	1.5	0.2	nd	nd	0.3	96.9*
G94 Δ17	green	12.3	0.9	2.4	59.1	nd	0.6	5.8	0.2	nd	0.9	1.2	nd	0.9	tr	nd	nd	9.1	93.7*
G32 Δ12	green/turq	9.3	0.4	1.9	50.9	nd	0.6	4.7	nd	nd	0.5	0.4	tr	4.5	0.1	nd	nd	12.1	85.8*
1674 Δ29	green	11.8	0.9	1.8	61.6	nd	2.3	5.4	0.2	nd	tr	0.5	nd	0.5	0.5	tr	nd	6.4	92.0*

nd = not detected, tr = trace

* Low analytical totals may be due to the presence of tin and/or antimony. One or both of these elements were detected by XRF but not by a visual examination of the EDX spectra. The soda values are also probably rather low, as noted in the text.

Table 6: EDX analysis of glass standards

		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	CoO	CuO	ZnO	SnO	Sb_2O_3	PbO	Total
Corning A	EDX	11.6	2.7	0.9	65.3	nd	3.0	5.0	1.1	0.2	1.1	0.9	nd	1.7	0.2	y	y	0.1	96.6
	Std	14.52	2.81	1.01	66.56	ns	2.93	5.3	0.8	.001	1.18	1.09	ns	1.22	ns	0.28	ns	.08	
Corning B	EDX	15.4	1.0	3.9	60.0	0.9	1.1	8.1	0.1	nd	0.2	0.4	nd	2.3	0.5	y	y	0.5	96.3
	Std	17.26	1.19	4.22	61.55	ns	1.1	8.71	0.1	.005	.28	.35	ns	2.7	ns	.04	0.4	0.4	

ns = not stated, y = detected by EDX, nd = not detected

Table 7: Inclusions found in Boss Hall and Buttermarket (St Stephen's Lane) samples

Sample ID	Colour in hand sample	Glass type	Description of section
Boss Hall			
G32 Δ2	translucent green	soda glass, contains copper and lead	vesicular, bubbles well-rounded and evenly-distributed
G32 Δ4	opaque green	soda glass, trace of lead	vesicular, very occasional small inclusions (unclear composition)
G32 Δ12	opaque green	soda glass, leaded with copper	lots of small inclusions, some of which are antimony-rich
G93 BM4	opaque green	soda glass, with copper, traces of lead	streaky, few inclusions
G94 Δ17	opaque green	soda glass, leaded, with copper	tin- and lead-rich inclusions
Buttermarket (St Stephen's Lane)			
1674 Δ29	opaque green	soda glass, with some lead, some copper. Slightly high K_2O content.	Sample taken from close to iron crust, showing vesicularity in this area. Otherwise, only slightly vesicular. Finely-dispersed inclusions, probably tin-rich. One large Cu-O inclusion (*c.* 100μ long).
3362 Δ18	translucent green	soda glass with significant copper and lead contents	Moderately vesicular; inhomogeneous, including two distinct streaked patches. One patch has high-atomic no contrast streaks which include Cu-O particles (*eg* particle a). The other also has high-atomic no contrast streaks but with a variety of particle compositions; Sn-Zn-Fe-Cu-O (particle b), Cu-O with traces of zinc and tin (particles c and d). Iron-rich crust with vesicular, corroded layer underneath.

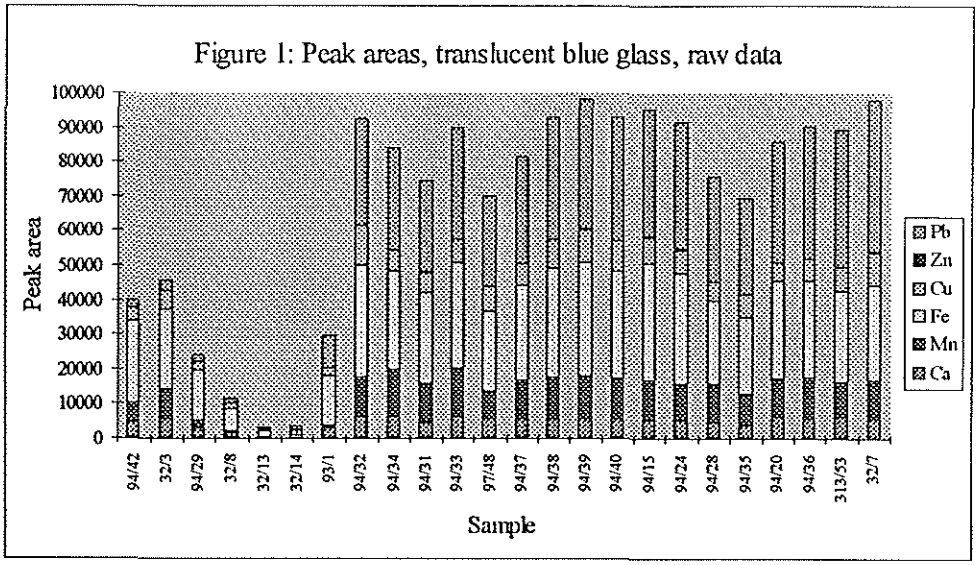


Figure 1: Peak areas, translucent blue glass, raw data
Peak area
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
94/42
32/3
94/29
32/8
32/13
32/14
93/1
94/32
94/34
94/31
94/33
97/48
94/37
94/38
94/39
94/40
94/15
94/24
94/28
94/35
94/20
94/36
313/53
32/7
Sample
Pb
Zn
Cu
Fe
Mn
Ca

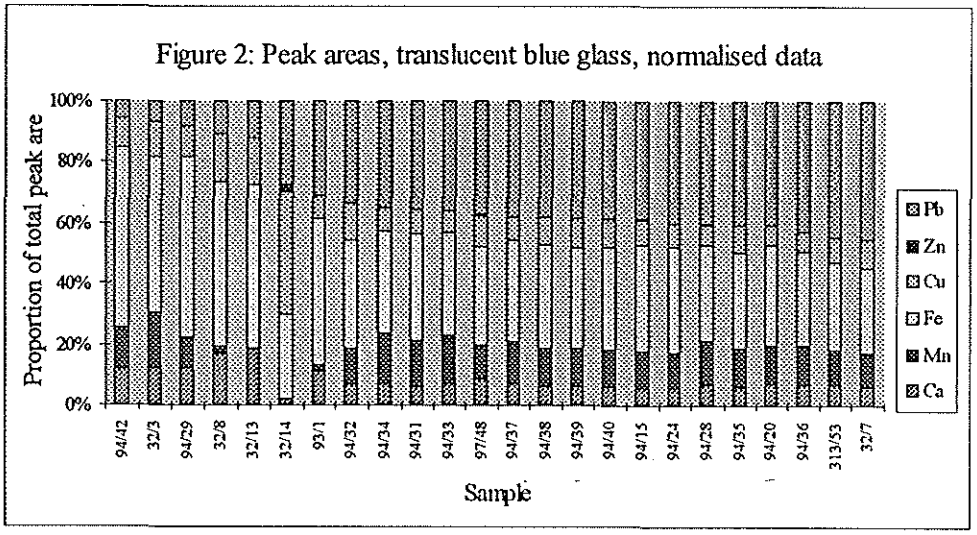


Figure 2: Peak areas, translucent blue glass, normalised data
Proportion of total peak are
100%
80%
60%
40%
20%
0%
94/42
32/3
94/29
32/8
32/13
32/14
93/1
94/32
94/34
94/31
94/33
97/48
94/37
94/38
94/39
94/40
94/15
94/24
94/28
94/35
94/20
94/36
313/53
32/7
Sample
Pb
Zn
Cu
Fe
Mn
Ca

Figure 3: Peak areas, translucent green segmented cylinder beads

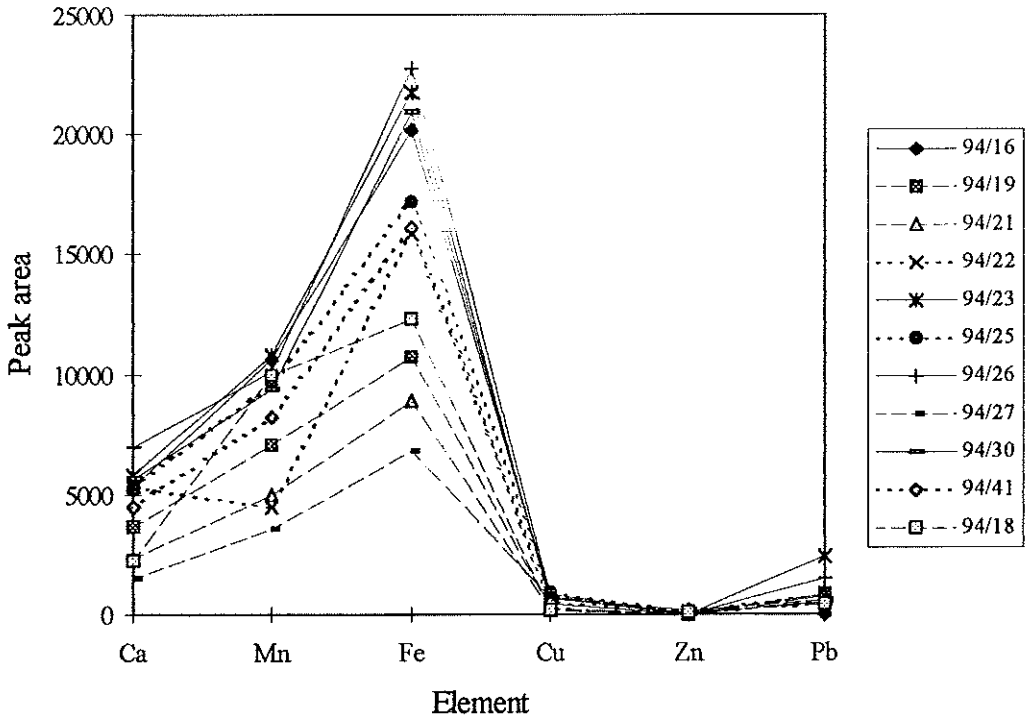


Figure 4: Translucent green beads (not segmented)

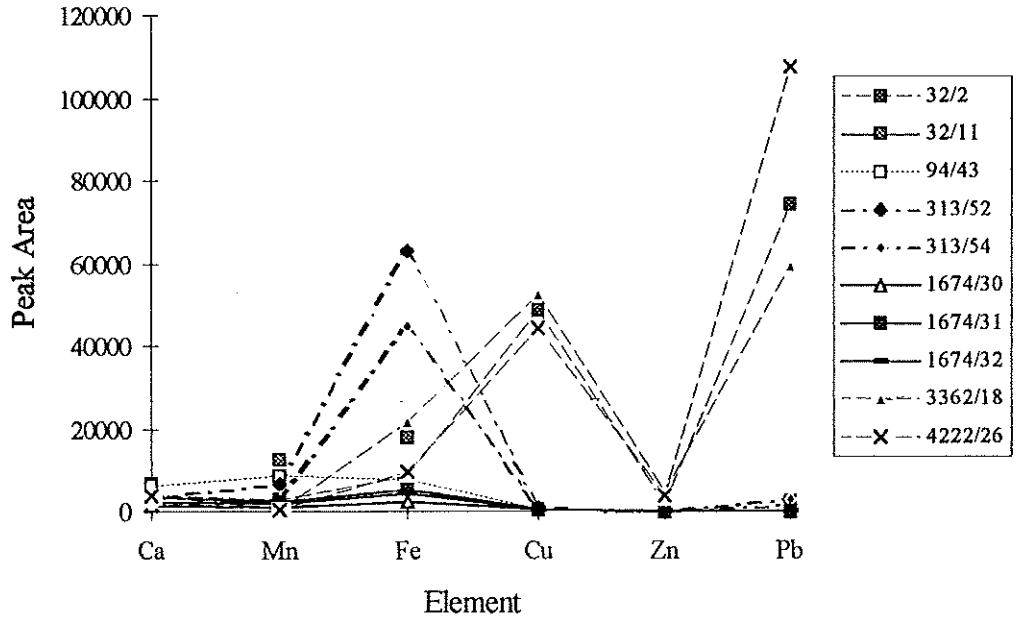
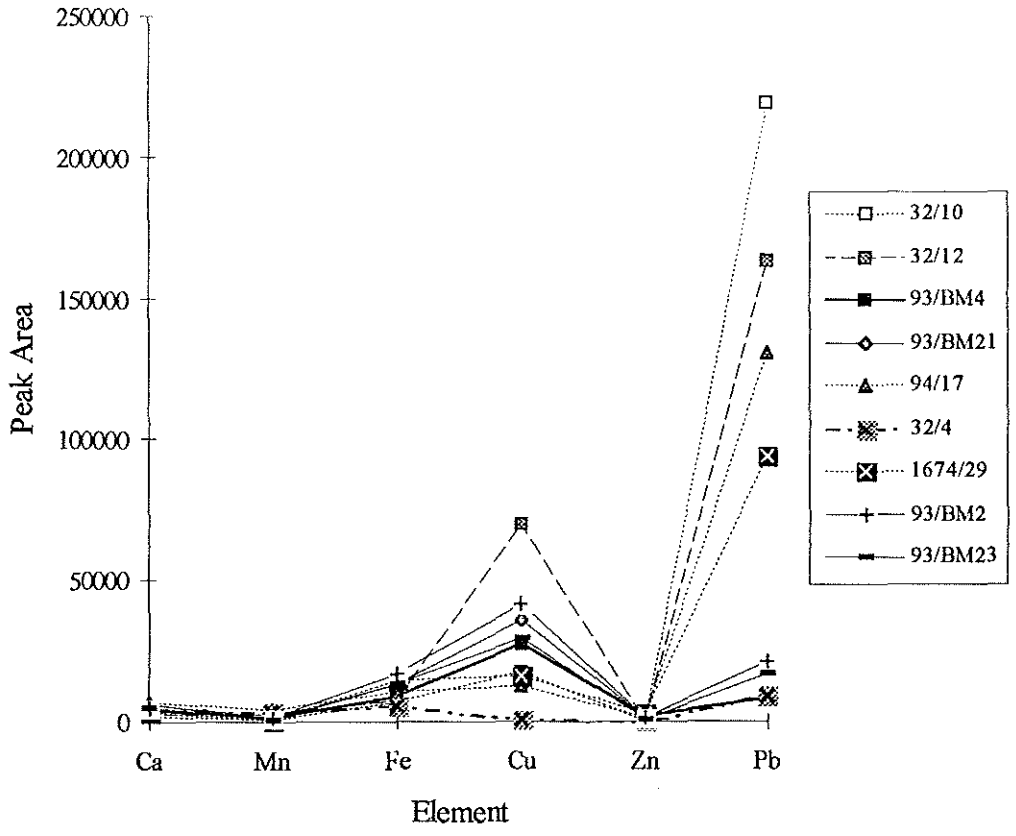


Figure 5: Opaque green beads



Catalogue: Boss Hall and Butter Market: glass, jet and crystal beads

Grave	No.	Form	Colour(s)	Manufacture	Inclusions	Surface
Boss Hall						
32	2	Drawn cylinder	Translucent green	Drawn		moderate abrasion
	3	Annular	Translucent blue	coiled	moderately vesicular	
	4	Disc	Pale opaque green		very vesicular, one large black 'flakey' inclusion	
	5	Cylinder	Opaque white, tr blue, opaque red	op red core, with tr blue and op white on outside	op white and tr blue = vesic, op red with black blobs/streaks	op white and tr blue = poor preserv
	6	Cylinder	Opaque white, tr blue, opaque red	as above	as above	as above
	7	Drawn cylinder	Translucent blue			
	8	Fragment	Translucent blue			
	10	Four-sided cylinder	Light opaque green	flat at both ends		poor preserv, irridescent
	11	Drawn cylinder	Pale transl green/yellow			poor preserv
	12	Fluted pentagonal cylinder	Opaque turquoise	well made, flat both ends		abraded
	13	Fragments	Transl blue			
	14	Fragments	Transl blue			
	50	Crystal				
35	9	Short cylinder, rounded	Transl blue, op red spots	flat surface both ends		ok

Catalogue: Boss Hall and Butter Market: glass, jet and crystal beads

Grave	No.	Form	Colour(s)	Manufacture	Inclusions	Surface
93	1	Melon	Transl blue	Break (where taken from rod?) well made		abraded
	49	Annular	Transl amber/brown, opaque white	v smooth doughnut	op white = crystalline, streams of bubbles in tr glass, spiral out	glossy, some wear on faces
	BM20	Annular	Pale transl green, op yellow and transl pale green reticella	well made, similar profile to above	bubbles spiral ?as in sf49; opaque yellow is crystalline	glossy
	BM2	Short cylinder, rounded	Pale opaque green	flat at both ends, very similar to other three opaque green		
	BM4	Short four-sided cylinder	Pale opaque green	see above		worn/rough
	BM21	Short pentagonal cylinder	Pale opaque green	see above		
	BM23	Short cylinder, rounded	Pale opaque green	see above, plus tool marks on side?		
	BM1	Disc (at Ipswich Museum)	Blue			
94	15	Drawn cylinder	Transl blue			
	16	Drawn cylinder, beaded	Pale transl green			
	17	Melon	Pale opaque green		vesicular	poor pres
	18	Drawn globular, triple	Pale transl green with gold?			
	19	Drawn cylinder, beaded	Pale transl green			
	20	Drawn cylinder	Transl blue			
	21	Drawn cylinder, beaded	Pale transl green			
	22	Drawn cylinder, beaded	Pale transl green with gold?			
	23	Drawn cylinder, beaded	Pale transl green			
	24	Drawn cylinder	Transl blue			
	25	Drawn cylinder, beaded	Pale transl green with gold?			
	26	Drawn cylinder, beaded	Pale transl green with gold?			
	27	Drawn cylinder, beaded	Pale transl green			

Catalogue: Boss Hall and Butter Market: glass, jet and crystal beads

Grave	No.	Form	Colour(s)	Manufacture	Inclusions	Surface
	28	Drawn cylinder	Transl blue			
	29	Annular fragment	Transl blue			
	30	Drawn cylinder, beaded	Pale transl green			
	31	Drawn cylinder	Transl blue			
	32	Drawn cylinder	Transl blue			
	33	Drawn cylinder	Transl blue			
	34	Drawn cylinder	Transl blue			
	35	Drawn cylinder	Transl blue			
	36	Drawn cylinder	Transl blue			
	37	Drawn cylinder	Transl blue			
	38	Drawn cylinder	Transl blue			
	39	Drawn cylinder	Transl blue			
	40	Drawn cylinder	Transl blue			
	41	Drawn cylinder, beaded	Pale transl green			
	42	Disc	Transl blue			
	43	Annular	Pale transl green	well made	bubbles in circles	abraded
	44	Globular	Opaque red, op yellow/white, pale transl blue		transl blue = vesic, op red has black spots	poor
	45	Cylinder	Opaque green, opaque red		opaque green has dark brown and white incl; opaque red has black streaks and incl	
	46	Cylinder	Opaque red; op yellow/op green reticella		opaque red has black streaks	
97	48	Drawn cylinder	Transl blue			
151	47	Disc	Transl green, opaque white		op white = crystalline, transl green = vesic	quite glossy, pitted on facing surfaces
313	51	Crystal				

Catalogue: Boss Hall and Butter Market: glass, jet and crystal beads

Grave	No.	Form	Colour(s)	Manufacture	Inclusions	Surface
	52	Coiled cylinder	Dark transl green			
	53	Drawn cylinder	Transl blue			
	54	Coiled cylinder	Presumably transl green (as sf52)			
	234	Jet (facetted)				
	235	Jet (facetted)				
	236	Jet (facetted)				
	98/F	Jet (facetted)				
Butter Market						
1674	29	Disc	Opaque green		vesic	very poor preservation
	30	Disc	Pale transl green	blob pushed through		
	31	Disc	Pale transl green	blob pushed through		probably pitted/abraded
	32	Disc	Pale transl green	blob pushed through		as above
3362	17	Annular (remains of wire slin	Pale transl green, op white with transl pale green reticella and op yellow with transl pale green reticella			irridescent
	18	Melon	Transl green			irridescent
4222	25	Short cylinder, rounded	Opaque red		black spots	irridescent
	26	Short cylinder, rounded	Transl green	well made (coiled)		irridescent
	31	Globular	Amber			
4275	24	Biconical	Pale transl blue/green	coil made		irridescent