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Summary

A selection of glass beads from burials in the Pagan Saxon cemetery sites at Beckford were analysed. The beads showed a range of shapes and colours, including both translucent and opaque beads. Qualitative analysis determined the range of colourants and decolourants used in their production and showed that they reflected a North European tradition of glassmaking.

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EXAMINATION AND ANALYSIS OF GLASS BEADS FROM BECKFORD, WORCESTERSHIRE

Introduction

Beads from a selection of burials at the Pagan Saxon cemetery sites of Beckford were examined. They included beads of non-glass materials such as amber, but only the glass beads were examined in detail and analysed. The number of beads found in each grave varied considerably and a representative selection was made of the beads, from a number of graves in each cemetery, of various colours and types.

The beads analysed were mostly monochrome, though two of the beads analysed were polychrome (see Appendix one). The interpretation of the analyses of the polychrome beads is more complex than for monochrome beads as the area analysed includes more than one glass colour. The colours of the beads were determined subjectively by eye but should provide a reasonable basis for comparison with each other and with the analytical results. The opacity of the beads varied from translucent to completely opaque and these have been divided into two groups: opaque and translucent, based on visual comparison.

Analysis

The beads were analysed using energy dispersive X-ray fluorescence (EDXRF) with an evacuated sample chamber. The elements analysed for were silicon (Si), phosphorus (P), potassium (K), calcium (Ca), titanium (Ti), manganese (Mn), iron (Fe), cobalt (Co), copper (Cu), zinc (Zn), lead (Pb), strontium (Sr), tin (Sn) and antimony (Sb). No attempt was made to analyse low atomic number elements such as sodium and therefore the bulk composition of the glass could not be determined. No sample preparation of the surface of the beads was possible due to the necessity for non-destructive analysis so any results from light elements would have been unreliable. The calcium results may also have been affected by contamination due to weathering and surface leaching. Since silicon is expected to be present at a relatively constant level in the beads as it is the major constituent of ancient glass it was used as an internal standard. The results were normalised by taking the ratio of the K-alpha peak height of each element (except for lead, when the L-alpha peak height was used) to that of the corresponding silicon K-alpha peak. The normalised results are listed in Appendix two. Only cobalt was not treated in this way as it was present, if at all, in very low concentrations and the peak for cobalt overlaps with the iron K-beta peak. Cobalt was therefore recorded as detected/not detected.

The method of normalising results to silicon is not so good when the glass has a high lead content. The lead causes the signal intensity from the light elements, particularly silicon, to be depressed relative to the other elements and this results in a much higher ratio figure for the other elements than in the beads with lower lead contents. This must be taken into consideration when comparing the ratios of high lead glass beads to other beads.

The ratio figures for each element quoted in Appendix two cannot be compared between elements (ie across the table) as the ratio bears little relation to the proportion of that element present. Different elements are excited with varying efficiencies by the primary X-rays, eg tin is excited far less than copper so the ratio will be a lot lower even when the amounts involved are similar. However, comparisons between analyses for a particular element (ie down the table) are valid.

Most of the elements recorded have an effect on the colour or opacity of the glass, the exceptions being phosphorus, potassium, calcium, titanium and zinc. Phosphorus, potassium and calcium are usually present in soda-lime-silica glasses as impurities in the main glass forming components. Titanium is also found at low levels in most glass and enters the glass melt as an impurity in the sand (silica) component. Zinc often enters the glass melt as an impurity or deliberate addition in the copper.

Results

Twenty-eight beads from Beckford were analysed by EDXRF (10 from cemetery A and 18 from cemetery B) and they were of varying colours and types (for full descriptions of the beads see Appendix one). These can be divided into thirteen colours:

Colour	Opaque	Translucent	Total
Blue (B)	-	1	1
Black (Bk)	2	-	2
Blue/Green (B/G)	1	-	1
Green (G)	2	-	2
Dark Blue (DB)	-	5	5
Light Blue (LB)	-	1	1
Dark Olive (DO)	-	2	2
Light Green (LG)	-	3	3
Purple (Pp)	-	1	1
'Colourless' (O)	-	6	6
White (W)	1	-	1
Yellow (Y)	1	-	1
Polychrome (P)	2	-	2

The analysed beads could be divided into six broad typological groups based on those types defined for beads from Buckland (Evison 1987: 61):

Type	Total
Cylinder	8
Globular	7
Annular	5
Disc	5
Melon	2
Biconical	1

The range of colours and bead types is similar to those from a number of other 6th and 7th century cemetery sites in Britain such as Sewerby (Hirst 1985: 62-85), Buckland, Dover (Evison 1987: 61-82), Mucking (Heyworth 1988) and Wakerley (Heyworth 1987).

Discussion

The beads are likely to be made of soda-lime-silica glass, and some will have had lead added at levels up to some 20-30%. This major element composition is a standard glass composition in the first millennium AD for all types of glass, vessels and windows as well as beads. The main components in the glass melt were sand, which provides the silica and possibly the calcium in the form of shell, and an alkali, either natron or a marine plant ash, which provided the soda.

The bulk composition of the glass beads cannot be determined from the elements recorded, however the titanium content may be a reflection of the silica source used, as it usually comes into the glass as an impurity in the sand, and variations in the titanium content may therefore equate with variations in raw materials sources. The titanium levels in the Beckford beads are mostly very low, with most of the beads having titanium ratio figures over 0.1 being due to the high levels of lead in the glass (see above). This means that there is no evidence for varying silica sources, though it does not necessarily follow that there was a constant silica source for the manufacture of all the beads. There do seem to be some variations in other elements, such as the potassium content, that may reflect variations in raw materials.

The other elements recorded were in the glass melt as either impurities in the main components or as deliberately added elements to achieve colouring or decolouring. Manganese, iron, cobalt, copper, tin, lead and antimony can all have a colouring effect, even when present in only very small quantities. Manganese and antimony can also act as decolourisers.

The production of coloured glass is extremely complex with a number of factors to take into account, such as deliberately added colourants or decolourants, the furnace conditions in which it is produced and the bulk composition of the glass. The colouring effect of different elements can be summarised as follows (for more detailed consideration see Bayley in press; Biek and Bayley 1979). The colour of iron-containing glass is strongly influenced by the furnace conditions, it will appear blue in strongly reducing conditions, green in less strongly reducing conditions and yellow or brown in oxidising conditions. This can be complicated by the presence of manganese which can either produce a wider range of colours including purple, or can act as a decolouriser to produce 'colourless' glass. Cobalt produces an intense blue colour, whereas copper produces a more turquoise blue or green in oxidising conditions. In reducing conditions copper can produce an opaque red or orange colour, though it may range through to a brown. Tin is usually associated with opaque glass as tin oxide gives an opaque white colour, though if the glass contains lead the lead-tin oxides that form will give an opaque yellow colour. Lead on its own does not actually produce colour but has an effect on the hue produced by colourants, and it plays an important role in the production of opaque glass. Antimony is another decolouriser in its reduced state, though in its oxidised state it produces opacity. Calcium antimonates are white, whilst lead antimonates are yellow.

There seems to be a shift from the use of antimony to manganese as a decolourant in the Roman period (Henderson & Warren 1983: 169) and it would therefore be expected that the Beckford beads would be decolourised by manganese. Antimony was detected in four beads at significant levels where it is not having an opacifying effect. Its presence may reflect the re-use of Roman glass in the manufacture of the beads, however exceptions are known where antimony was used as a decolourant in post-Roman beads (eg Henderson and Warren 1983: 169). The use of manganese as a decolourant in the majority of the Beckford beads can be seen from the iron:manganese (Fe:Mn) ratios. All the glass contains detectable amounts of iron which would have coloured the glass, unless masked by a stronger colouring agent, but its effect could be neutralised by the addition of manganese. The 'colourless' beads from graves 13 and 58 (cemetery B) have a Fe:Mn ratio of about one, which suggests that the manganese was added deliberately in the correct proportion to decolourise the iron. However the green and blue-green beads mostly have high Fe:Mn ratios and the iron colour is dominant.

One bead from grave 24 (cemetery B) was a translucent purple colour. This was caused by the manganese content which is high enough to completely drown the effect of the iron content, the iron:manganese ratio is well below one.

Iron containing glass can be a range of colours depending on the atmosphere in the furnace. In slightly reducing conditions it will produce a light green or blue-green colour such as in the beads from graves 9 and 23 (cemetery A) and graves 3 and 39 (cemetery B). The stronger the reducing conditions the more blue the resulting glass and the bead from grave 16 (cemetery B), in the absence of a significant quantity of copper, is likely to be coloured by iron.

Copper also produces a range of colours in glass. Copper in solution in a lead-rich glass gives a green colour as in the beads from grave 16 (cemetery A) and grave 6 (cemetery B).

The blue and dark blue beads are all coloured by cobalt which is detectable in all cases. Cobalt is capable of producing an intense colour even when present at very low concentrations (parts per million level) and it is sometimes difficult to confirm its presence. However the cobalt blue is a distinctive deep blue colour and all six translucent blue and dark blue beads were of this characteristic blue.

The black glass beads from grave 3 (cemetery B) have a high iron content which produces the colour. Black glass is usually produced from mixing together scraps of glass of different colours, and there is some variation in the composition of the two black beads which may support this argument.

The majority of the opaque beads contained significant levels of tin and lead. Lead does not actually produce any colour itself in the glass but it is an important part of the mechanism for the production of opaque glass as its presence allows the opacifying agent to dissolve in the melt and precipitate from it in a controlled way as it cools which produces an even colour and opacity. The opaque yellow bead from grave 66 (cemetery B) was produced by precipitating lead tin oxide. This bead must have been heated below 900 degrees centigrade as above that temperature the pigment breaks down and tin oxide is produced, giving a white colour and this reaction cannot be reversed. The opaque white bead from grave 9 (cemetery A) has a much lower lead level than the opaque yellow bead and must have been deliberately made using tin oxide; it is not over-heated yellow. There is no evidence from Beckford for the use of antimony as an opacifier. This is expected as antimony is usually present as an opacifier in Roman beads and is replaced as an opacifier by tin in the late Roman and post Roman glasses.

One opaque bead from grave 66 (cemetery B) had a much higher lead content than the other beads, possibly as high as 20 - 30% lead. For this bead the method of dividing the elemental gross intensities obtained from XRF analysis by the silica figure is not completely satisfactory (as explained above), hence the high ratio figures for all other elements in these beads.

The polychrome beads were both basically opaque, though one had translucent glass added as decoration in trails. The polychrome beads were opacified by tin, as were the monochrome beads. The similarity in composition between the monochrome and polychrome beads can be used to suggest a common manufacturing tradition for the two types of bead, though there are far fewer polychrome beads at Beckford than from similar sites such as Buckland.

The interpretation of the analyses of the polychrome beads is not as simple as that from the monochrome beads as the analysis usually includes at least two colours of glass. However in most cases the analyses show that the colourants present in the polychrome beads are consistent with what would be expected from the monochrome beads for the colours analysed.

Conclusions

The colours observed in the Beckford beads are all explicable from the composition of the glass. These compositions are similar to those from other comparable sites of this period. The production of the beads seems to follow the Germanic tradition of glassmaking which is what would be expected at Beckford. There is some evidence that antimony continues in use as an opacifier in the Mediterranean world at this period so its absence in the majority of the Beckford beads supports the North European origin for the beads.

The similarity of evidence from other contemporary cemetery sites such as Mucking, Wakerley, Buckland, and Sewerby leads to the conclusion that the beads in circulation in this country in the Pagan Saxon period were all part of the same manufacturing tradition. They are usually associated with a northern European, Germanic tradition. This clearly reflects the dominant area of contact for Britain in this period.

The similarity of analyses of beads from the various cemetery sites means that it is now possible to predict the elements used to produce the colours in the bead assemblages of this period. It will perhaps be necessary to begin to consider the major element composition of the beads to take the study of the manufacturing traditions further and begin to identify source areas if this is possible.

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APPENDIX ONE

Catalogue of beads analysed by EDXRF

Grave	No.	Description	Opacity	Colour
B g3	6	annular	translucent	blue
A g16	65	cylinder	translucent	dark blue
A g9	31	cylinder	translucent	dark blue
B g102	256	biconical	translucent	dark blue
B g83	232	annular	translucent	dark blue
B g3	6	annular	translucent	dark blue
B g16	55	disc	translucent	light blue
A g23	93	globular	translucent	light green
A g9	31	globular	translucent	light green
B g3	6	globular	translucent	light green
B g24	68	annular	translucent	purple
B g58	158	cylinder	translucent	colourless
B g58	158	globular	translucent	colourless
B g13	43	cylinder	translucent	colourless
A g23	93	globular	translucent	colourless gilt
A g7	18	globular	translucent	colourless gilt
A g7	18	globular	translucent	colourless gilt
B g3	6	melon	opaque	black
B g3	3	melon	opaque	black
B g39	110a	cylinder	opaque	blue-green
B g39	110a	cylinder	opaque	dark olive
B g6	13	cylinder	opaque	dark olive
A g16	65	disc	opaque	green
B g6	13	cylinder	opaque	green
A g23	93	disc	opaque	yellow with red & dark green
B g24	68	disc	opaque	yellow & colourless
A g9	31	disc	opaque	white
B g66	178	annular	opaque	yellow

APPENDIX TWO

Results of EDXRF analysis, all figures normalised to silicon, except cobalt, which is either detected (+), not detected (-) or uncertain (?).

The symbols representing bead colour (in column labelled 'Col') are as follows: B - Blue, Bk - Black, DB - Dark Blue, DO - Dark Olive, G - Green, LB - Light Blue, LG - Light Green, O - 'Colourless', P - Polychrome, Pp - Purple, W - White, Y - Yellow.

The symbols representing bead opacity (in column labelled 'Opac') are as follows: T - Translucent, O - Opaque.

Number	Col	Opac	P	K	Ca	Ti	Mn	Fe	Co	Cu	Zn	Pb	Sr	Sn	Sb
B g3/6	B	T	0.03	0.26	0.98	0.05	0.10	0.51	+	0.22			0.20	0.06	
A g16/65	DB	T	0.02	0.06	0.77	0.03	0.59	0.88	+	0.25		0.30	0.11		
A g9/31	DB	T	0.03	0.07	0.83	0.02	0.33	0.62	?	0.19		0.68	0.07		0.15
B g102/256	DB	T	0.04	0.17	0.96	0.08	0.13	1.81	+	0.23		0.25	0.14		
B g83/232	DB	T	0.02	0.16	0.80	0.05	0.21	0.77	+	0.14		0.06	0.13		
B g3/6	DB	T	0.03	0.11	0.81	0.04	0.30	0.96	+	0.12		0.10	0.14	0.06	
B g16/55	LB	T	0.03	0.13	0.64	0.05	0.14	0.59	-			0.06	0.09		0.08
A g23/93	LG	T	0.06	0.09	0.92	0.04	0.77	0.87	-				0.18		
A g9/31	LG	T	0.04	0.10	0.85	0.04	0.55	0.68	-				0.16		
B g3/6	LG	T	0.05	0.17	1.07	0.06	0.92	1.08	-	0.08		0.08	0.23		
B g24/68	Pp	T	0.09	0.45	1.19	0.11	2.64	1.70	-	0.36			0.26		
B g58/158	O	T	0.02	0.06	0.93	0.04	0.63	0.72	-				0.16		
B g58/158	O	T	0.05	0.11	0.80	0.04	0.57	0.57	-				0.17		
B g13/43	O	T	0.02	0.06	0.75	0.03	0.50	0.58	-	0.03		0.03	0.16		
A g23/93	O	T	0.05	0.06	0.65	0.11	0.27	1.44	-				0.14		
A g7/18	O	T	0.02	0.05	0.54	0.02	0.09	0.40	-				0.08		
A g7/18	O	T	0.04	0.09	0.56	0.05	0.13	0.61	-				0.14		0.07
B g3/6	Bk	O	0.09	0.24	1.42	0.16	0.47	8.83	-	0.16		8.13	0.06	0.04	
B g3/3	Bk	O	0.13	0.31	1.12	0.20	0.42	9.32	-			7.48	0.08		
B g39/110a	B/G	O	0.03	0.16	0.70	0.05	0.13	0.81	-	0.81	0.26	3.30	0.10	0.15	
B g39/110a	DO	O	0.05	0.12	0.97	0.09	0.63	3.84	-	0.11		0.17	0.11		
B g6/13	DO	O	0.03	0.10	0.99	0.07	0.66	4.02	-				0.16		
A g16/65	G	O	0.04	0.10	0.71	0.03	0.20	0.68	-	2.18	0.23	2.31	0.07	0.06	
B g6/13	G	O	0.09	0.33	1.04	0.09	0.62	1.23	-	1.58		2.70	0.13	0.13	
A g23/93	P	O	0.10	0.19	0.89	0.20	0.80	7.63	-	2.09	0.15	5.81	0.12	0.12	
B g24/68	P	O	0.02	0.07	0.48	0.02	0.03	0.24	-			0.29	0.07	0.04	0.05
A g9/31	W	O	0.10	0.17	1.43	0.12	1.21	1.96	-	0.15		0.66	0.23	1.90	
B g66/178	Y	O	0.09	0.58	1.07	0.12	0.46	1.38	-	0.25	0.21	11.35	0.14	0.23	