

# GLASSWORKING AT ÅHUS, S. SWEDEN (EIGHTH CENTURY AD)

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## Introduction

In the discussion of the character of Late Iron Age society in Barbarian Europe and its transformation into the Medieval society the existence and the role of specialized craftsmen and merchants/traders plays an important role (cf Das Handwerk 1981, see also Brumfiel & Earle 1987 and Brumfiel 1987 for more general considerations). This is the case in Northern Europe no less than in other parts of the subcontinent. Opinions are most strongly opposed in the debate whether artisans were integrated in local society ie if they were free men in the villages or belonged to the local big man's household or whether they on the contrary formed separate groups or groups with others, eg traders/merchants which essentially must be understood as existing outside local society.

For lack of a relevant source material this discussion has for some time come to a standstill. It is fortunate that during the last years new and important material has been forthcoming (cf Ulbricht 1978, Christophersen 1980, Ambrosiani 1981, Brinch Madsen 1984). Here we shall focus on the production of glass ornaments - above all beads. From several localities during the last two decades debris from bead production have been reported from Late Iron Age and Early Medieval sites in Northern Europe (Lundström 1976, Dekówna 1980a). From the majority of these sites material is scarce and in many cases highly doubtful (L'vova 1970, Cnotliwy et al 1983:232 ff). A small number of sites however have yielded highly convincing finds and find contexts (Hougen 1969, Näsman 1979).

## Problems

The basic questions for this study of a bead working material from Southern Scandinavia (eighth century AD) are the following.

1. was bead making a simple or a highly sophisticated (handi)craft?

2. did the production involve more than one skilled craftsman?
3. were bead makers resident artisans or migrant?
4. what do techniques tell about the cultural background of the artisans?
5. which is the place of this production in relation to the European development of glass working
6. how close is the relationship between a glass working material from the Baltic region and the contemporary workshops operating in the North Sea region like Ribe?

## Excavation

During the years 1979-1984 we had the opportunity to excavate an important early eighth century site with a rich relevant find material near Åhus in Northeastern Scania (Southern Sweden) (Callmer 1982, 1984, 1988). This site occupies a vast area - more than four hectares (fig 1) with a high variation in density of workshop debris, mostly from glass- and metal-working. There had probably also been antler-working and smithing going on at the site. The site probably lacks all constructional traces of permanent settlement which seems to indicate that it was only seasonally occupied by artisans and traders. Traces of craft production were found in several different concentrations including an obviously very densely exploited zone on the river bank which is the northern boundary of the site area. Some important finds of Wodan Monster sceattas and numerous weights suggest frequent visits by traders. It is further reasonable to think that since this site is close to the coast it was frequently visited by the local population of the plain district hinterland. A total of 630 m<sup>2</sup> was excavated including both an open surface and numerous trial trenches to give information about the whole site area. The remains of only a few constructions were found, mostly pits and hearths. Two severely damaged ovens were found as well as numerous pieces of completely destroyed ones. The coins already mentioned and other finds date the site to the first half of the eighth century.

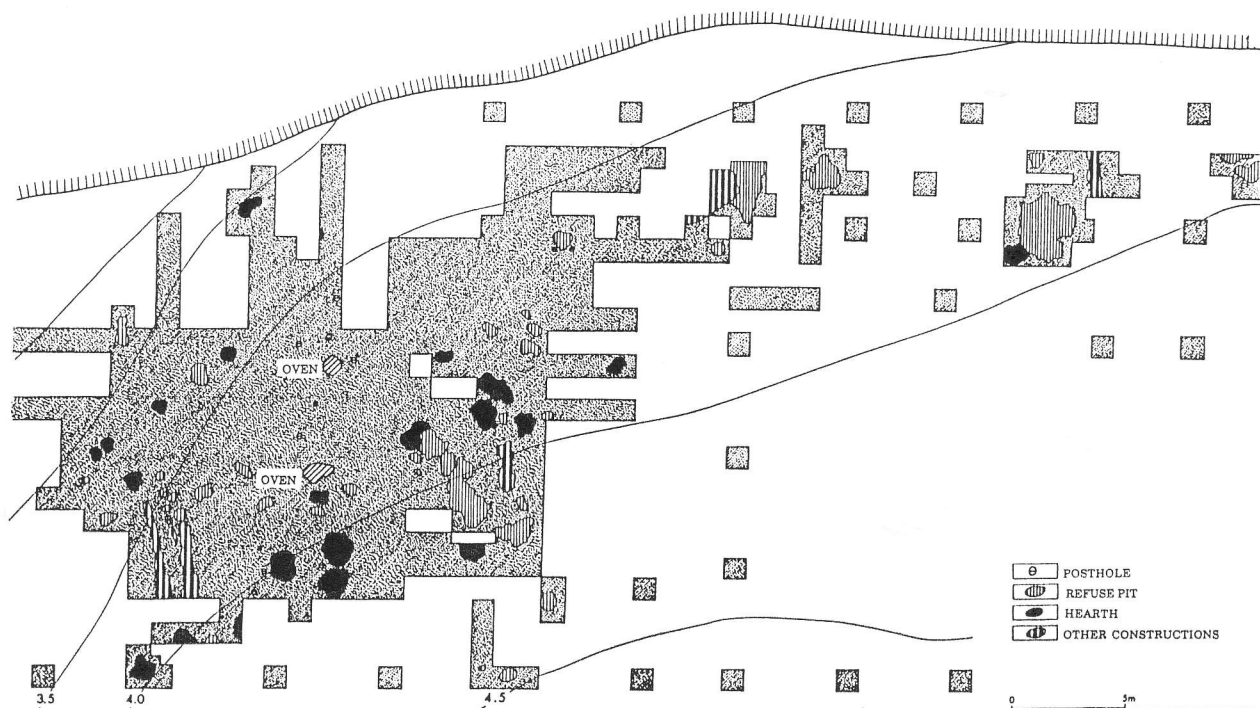


Fig 1. The excavation area on the lower reaches of River Helge Å (ie the Holy River), NE Scania, Sweden.

## Beadmaking techniques

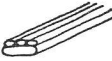
The technical analysis was conducted by macroscopic and microscopic inspection of products and production waste. The frequent occurrences of round, rounded oval or pointed oval bubbles in the glass metal (cf Herschend 1973) as well as colouring variations (for the explanation and chemical nature of these variations see below) provided a very good basis for a study of the technical production procedures. There were no good motives to work with thin sections from this material (cf Dękówna & Szymański 1971, Dękówna 1980). With the aim to follow the different stages in the production sequence the glass was classified with reference to its technical features, physical form/shape, colour and opacity. After several drafts a classification system was laid down in 1980 and was found adequate. Subsequently all glass was classified according to this (tab 1).

Glass-working at this site does not include the production of glass metal; there is nothing to indicate this primary production process. All material found is connected with secondary glass-working. This means that the production of glass ornaments at Åhus does not differ from other glass-working sites in Barbarian Europe. The finds are numerous and varied. The number of counted glass objects is no less than 71,896. It is however necessary to discount 856 sherds of glass vessels which we mostly do not think were connected with this production.

Glass-working here was based on imported prefabricated materials of three different kinds. Most important of these was blue transparent glass. Ca 78% of all production finds are of this colour and transparency or are combinations in which blue glass is a major component. Blue glass occurs most commonly as small chips or splinters (47% of the find material). When the fractions are bigger it can be seen that many, if not all, have been struck from rounded glass cakes (fig 2) not unlike the round glass smoothstones occurring frequently in North-western and Northern Europe from the tenth century on. Raw glass was transported in the form of cakes also much later (cf Charleston 1963). To judge from the micro debitage found on the site the crushing and chipping was done there - at least partly (cf Fladmark 1982). Most probably also glass rods of blue and yellow opaque glass were imported (cf Lundström 1976:10). Quality and technique could indicate that these rods have a common origin with the millefiori rods commented on further on. A special kind of splinter occurring at the site shows that they were broken in fractions on the spot in order to make the handling easier. This type of splinter comprises an incomplete transverse section and a fraction of one side of the rod.

A much smaller group is formed by tesserae and fragments of tesserae (919 pieces) (fig 3). They were obviously also crushed to make them more easy to work with. Almost half of this number are goldfoil tesserae whereas other colours occur only sparingly.

**Table 1. Classification of waste material from glassworking.**

| WASTE MATERIAL FROM GLASS WORKING                                          |                       |                                                                                     |                          |                                                                                     |
|----------------------------------------------------------------------------|-----------------------|-------------------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------------------------------|
| SHAPES                                                                     |                       |                                                                                     |                          |                                                                                     |
| A. CHIPS                                                                   | 1.                    |    |                          |                                                                                     |
| B. SPLINTERS                                                               | 1.                    |    |                          |                                                                                     |
| C. DROPS                                                                   | 1. GLOBULAR           |    | 2. REGULAR DROP          |    |
|                                                                            |                       |                                                                                     | 3. IRREGULAR             |   |
|                                                                            |                       |                                                                                     | 4. FRAGMENTARY           |  |
| DA. RODS                                                                   | 1. RECTANGULAR/OVAL   |    | 2. ROUND                 |    |
|                                                                            |                       |                                                                                     | 3. ANGULAR               |   |
|                                                                            |                       |                                                                                     | 4. QUADRANGULAR          |  |
| DB. RODS                                                                   | 5. RODS WITH SWELLING |    |                          |                                                                                     |
| DC. ROD SPLINTERS                                                          | 6. BREAKING SPLINTER  |    |                          |                                                                                     |
| DD. ROD ENDS                                                               | 7. INTACT             |    | 8. TAIL MISSING          |    |
|                                                                            |                       |                                                                                     | 9. OTHERWISE FRAGMENTARY |   |
| E. TESSERAE                                                                | 1. CUBE               |    | 2. OTHER SHAPE           |    |
|                                                                            |                       |                                                                                     | 3. FRAGMENTARY           |   |
| F. PARTLY OR COMPLETELY SLAGGED LUMPS                                      | 1.                    |    |                          |                                                                                     |
| G. PUNTY GLASS                                                             | 1.                    |  |                          |                                                                                     |
| H. PRODUCTION WASTE OF SMALL DIMENSIONS NOT CLASSIFIABLE ACCORDING TO A-G. |                       |                                                                                     |                          |                                                                                     |
| MATERIAL                                                                   |                       |                                                                                     |                          |                                                                                     |
| I. MONOCHROME INCL. GOLD FOIL TESSERAE                                     |                       |                                                                                     |                          |                                                                                     |
| II. COMPOSITE LINEAR RODS                                                  |                       |  |                          |                                                                                     |
| III. CABLES (RETICELLA RODS)                                               |                       |  |                          |                                                                                     |
| IV. MILLEFIORI RODS, RECTANGULAR                                           |                       |  |                          |                                                                                     |
| V. MILLEFIORI RODS, CYLINDRICAL                                            |                       |  |                          |                                                                                     |
| PRODUCTS                                                                   |                       |                                                                                     |                          |                                                                                     |
| 1. UNDECORATED WOUND BEADS                                                 |                       |  | 1. INTACT                | 2. FRAGMENTARY                                                                      |
| 2. DECORATED WOUND BEADS                                                   |                       |  | 1. INTACT                | 2. FRAGMENTARY                                                                      |
| 3. MILLEFIORI BEADS.                                                       |                       |  | 1. INTACT                | 2. FRAGMENTARY                                                                      |

In a few cases it has been possible to observe that there is still mortar adhering to the tesserae which indicates that at least some of these mosaic stones were in fact robbed from mosaics in Western or Southern Europe and the Mediterranean region (cf Theophilus 1961).

The third group of imported prefabricated glass material are millefiori rods (902 pieces). More than one third of the finds of these rods are of the classical type with blue and yellow chequer pattern within a red frame. Other frequent patterns are various eye and flower designs (cf Callmer 1977;98-99).

It is also possible that a third type of composite rods was another imported prefabricated material. They are cylindrical rods showing the pattern of a rayed eye. Several variants occur in the material but eye decoration only occasionally occurs on beads (eye motifs are frequent in later finds; cf Callmer 1977).

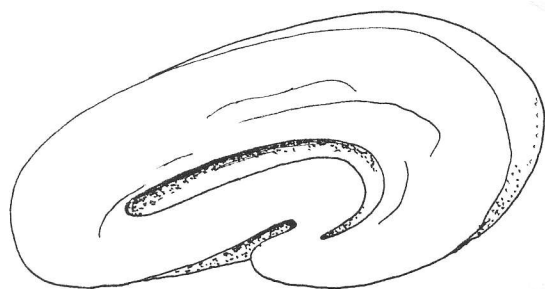


Fig 2. Glass raw material in the shape of a cake of blue transparent glass (reconstruction).

Beads were made at this site according to two different technical procedures. The glass metal was warmed and kept hot in a metal pan rather than in a crucible since no connected ceramic material was found. Most commonly used was without doubt the winding technique. Formable, soft glass was collected on to a punty rod (Gam 1990). The glass is wound or twisted round a rotated small iron spit. The latter is coated with clay. The additional tools used were diverse pairs of tweezers and possibly a pair of light thongs. The technique is difficult since it demands a very rapid and dexterous handling of the glass material and control of the necessary heat as a result of the thermal properties of the glass. After this primary stage in the procedure it is always necessary to reheat the bead and the products must then cool sufficiently slowly in order not to break. Most beads at this site were annular or barrel shaped (fig 4).

The decoration of beads at Åhus mainly made use of

linear ribbon patterns. Above all we meet patterns of red and white, sometimes including yellow. In order to decorate the beads with this type of ribbon decoration a special composite decoration rod was made (fig 5). A blue rod was flattened and on it a number of white and red and sometimes also yellow rods were applied. This composite decoration rod was then further drawn out to the desired dimension. The rod was subsequently applied to the bead. Standards in this workshop were high, and decoration which was not level with the smooth surface of the bead was not accepted. The bead consequently had to be reheated and turned until the decoration was level with the surface (fig 6). The blue portion of the decoration rod had the function to make the adhesion more easy.

Quite frequently we find reticella rods at Åhus (878 pieces found), whereas beads decorated with reticella occur only very occasionally (fig 7). This technique was fully mastered and all stages in the production of these decoration rods in two or more differently coloured glass materials can be followed. The rods were twisted and then the rod turned and rolled in a heated state on a smooth surface to produce a perfect or almost perfect cylinder. This decoration technique as well as the ribbon technique described above show us that the skill to draw rods of glass was fully mastered by the artisans visiting the Åhus site. It is important to remark on this since modern experiments to remake beads of the type dealt with here have failed to master the rod production technique (cf Gam 1990).

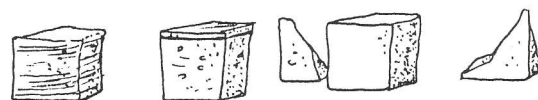


Fig 3. Tesserae.

The winding technique and the decoration techniques described presuppose a very close control of heat which could only have been reached with the help of an oven and it is most unfortunate that our knowledge of the oven constructions used at Åhus is so incomplete. Numerous finds of end pieces of rods and drops of glass are directly connected with work under strong heat (use of blowpipe?).

The procedures of rod drawing and rod twisting give us a very welcome insight into the organisation of bead production. It is obvious that the work could not be done by one or two artisans. Most probably

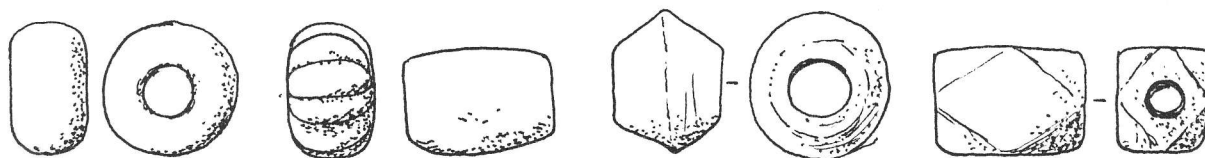


Fig 4. Undecorated monochrome beads.

there would have been three or four people working together. It takes two people to draw rods and the turning of reticella rods is best done by two. These two artisans must have been served by one or two helpers who tended the oven.

The second technical bead making procedure used at Åhus is the melting together of cut pieces of millefiori rods to beads (fig 8). This technique is used in the classical manner with combinations of two different patterns on each bead. The cut pieces are placed when set in two or more rows according to the rules so that they are identical on the diagonal axis (beads of this type occur already in the late Hellenistic period, Alekseeva 1982:35ff) (fig 9). The artisans had full mastery of the technique but there were relatively few beads made using this procedure in comparison to the winding technique. It may be that it was less common that there were mistakes in the production of the millefiori beads but contemporary grave finds also show us that the frequency of these beads was much lower than that of wound beads.

### Chemical and physical analysis

At an early stage of the study of this material it was realized that for several reasons it was necessary to combine this technical analysis of the material with a chemical and physical analysis. Most important was the question of the place of this bead-making material in the development of glass-making and bead-making material in the development of glass-making and bead-making traditions in Europe and the Mediterranean. Later, in the eight century, the dominance of wound beads in Northern Europe is turned over by an inundation of beads made according to different procedures. These new beads are mainly or completely imports (Callmer 1990). Later in the ninth century and later wound beads of North-european make reappear.

A second reason is that the Åhus material has very close parallels in the early eighth century find material from Ribe in Southwestern Denmark (Näsman 1979). The parallels are so close both with

regard to techniques and to design that we must assume that the artisans behind these products shared the same mental templates and had the same training.

A third reason is that the technical analysis shows us a craft with a very high standard of professional skill. It also shown us a system of very fixed rules regarding techniques, shapes and colour combinations. It is important to know whether this traditionality corresponds to a conscious choice of material with regard to their physical and chemical properties.

Another major problem is the systematic secondary use of imported, presumably often old, glass and the reheating of this material, as well as the reheating and working of different pre-fabricated glass material. It must be a relevant question to ask whether the glass workers mastered the problems because they were already familiar with the technical characteristics of the glass or on the contrary they were unfamiliar with them and had to experiment and find *ad hoc* solutions to the problems. This must have an important bearing on the training of these glass workers, their standard of reasoning and the character of the supply of raw materials (stable or unstable).

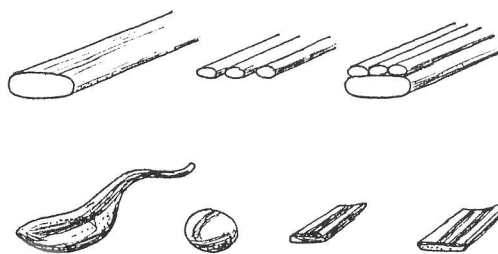


Fig 5. Decoration rods.

### Electron probe microanalysis and scanning electron microscopy

Micro-samples of glass of c 1 mm in length were mounted in epoxy resin and polished through a series of grades to 0.5 micron diamond paste.

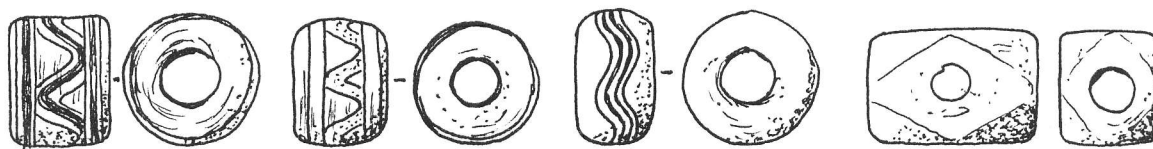


Fig 6. Decorated beads.



Fig 7. Reticella rods in different stages of production.

Samples were taken from tesserae, monochrome rods, millefiori rods and polychrome cables ("reticelli"), melted rods, vessel fragments, monochrome glass beads, polychrome glass beads and melted by-products from glass bead production. The block of epoxy resin containing the samples was coated with a thin layer of carbon so as to prevent any distortion and deflection of the electron beam during analysis. The electron beam was defocussed to c 80 microns so as to minimise the loss of sodium from the glass. Each sample was analysed a minimum of three times and the results are an average of these compositions. The systems used were a Cambridge microscan 9 electron microprobe with two wavelength dispersive crystal spectrometers and a Cameca SU30 with combined wavelength and energy-dispersive spectrometers and a scanning electron microscope. The systems were operated at 20kV and 40nA. For quantitative work the Cambridge was calibrated using a combination of Corning, European Science Foundation and British Glass Industry Research Association glass standards.

## Results

The results will be discussed in global terms according to the gross compositional types and the minor components which suggest the use of particular raw materials. The overall results will then be described according to the colorants and opacifiers detected. Since space is limited, the full list of these results and more will be published elsewhere (Henderson, forthcoming).

### Principle compositional types

Three principle compositional types of glass were

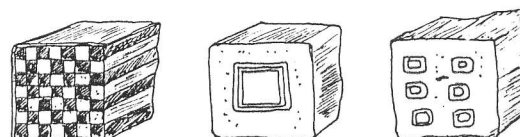


Fig 8. Millefiori rods.

found. A high proportion were of a soda-lime-silica composition with relatively low magnesia and potassium oxide levels, generally described as low magnesia glasses (or LMG for short). The second compositional type, specifically in opaque yellow glass, contained high lead oxide levels, correspondingly lower contents of soda, calcium oxide and silica and opacified by lead tin-oxide crystals ("PbSnO<sub>3</sub>").

The third compositional type of glass was defined by the presence of relatively high levels of magnesia and potassium oxides; all examples of this type are orange, red or pink. There are, however, also glasses in red and pink glasses which do not contain the high levels of potassium and magnesium oxides. The high magnesia glasses are known as HMG; other ancient HMGs (such as 2nd millennium BC. Egyptian and Middle Eastern glass) often contain higher levels of MgO than found here. Figure 10 shows a plot of weight % potassium oxide against weight % magnesium oxide in Åhus glass. Although some LMGs come close in their MgO levels to HMG, the associated elevated potassium oxide levels clearly distinguish between the two compositional types. HMG is similar in other respects to LMG, but the recipe differs significantly in that the elevated MgO level would have been derived from a plant ash alkali source rather than a MgO-containing mineral alkali source (Turner 1956 and Henderson 1988).

### A. Colourless glass

A single sample of colourless glass was found to contain relatively low levels of potential colorants (manganese and iron oxides are present at 0.3% and 0.4% respectively). Antimony (as oxide) was detected at 0.5% and probably acts as a decolorant in the

glass. The only other glasses with comparably low levels of manganese and iron oxides are opaque yellow and opaque white (with one exception), inferring that a stock of base glass with relatively low content of potential colorants was used in their manufacture and that the raw materials were specially selected so that the opaque colours would be uncontaminated by colorants. A translucent yellow-green glass bead with comparably low iron and manganese oxide levels, but which contains no detectable antimony trioxide was found.

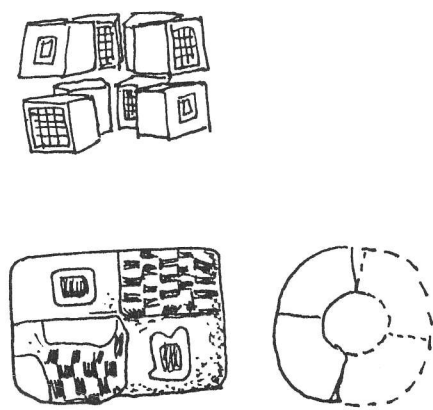


Fig 9. Millefiori bead.

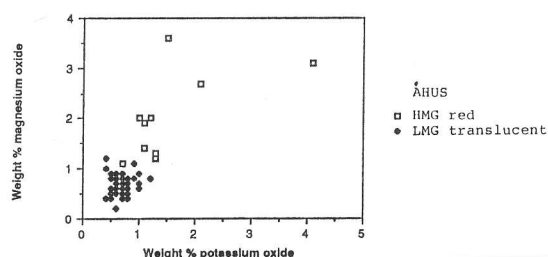


Fig 10. Weight % MgO vs weight % K<sub>2</sub>O in Åhus red high magnesium oxide glass and translucent low magnesium oxide glass.

## B. Translucent blue and green glasses

### *Bi Translucent blue glass*

The level of detection for CoO in a soda-lime-silica matrix under the conditions employed was c 600 ppm which is easily sufficient to cause a blue colour in soda-lime-silica glasses (Henderson 1985). Cobalt oxide was detected in 6 multi-coloured rods (3 millefiori rods and 3 cables), 5 failed glass rods, 4 monochrome glass beads, 4 polychrome glass beads and 2 fragments of bead-making debris. It is worth

noting that in some of the blue glasses analysed no cobalt oxide was detected, which suggests that ferrous oxide acted as a colorant instead or that cobalt oxide was at very low (undetectable) levels. However, in those glasses in which cobalt was detected the positive correlation between the % ferric oxide and % manganese oxide shows that a geologically similar manganiferous source of cobalt mineral was used to make all the artefact types in which cobalt was detected (fig 11). All the translucent blue glasses analysed were found to contain antimony trioxide mainly at levels between c 0.5 and 1.0% which suggests that an antimony-rich raw material, such as Roman tesserae, was used in their production (Henderson, in press) (fig 12). The blue coloured glass in the polychrome glass beads analysed were found to contain higher levels of antimony oxide than the rest.

### *Bii Translucent green glass*

The green glasses analysed all contained manganese, iron and copper oxides at varying levels. The paler green levels would be coloured by a balance of these three colorants, with the final colour being dependant on a number of factors including the maximum temperature of the furnace, the gaseous atmosphere of the furnace through the firing cycle, the length of the firing cycle, the precise balance of each of the colorant oxide levels and (where relevant) the presence of any crystallites in the glass which would render the glass opaque (see below). Many translucent green glasses also contained traces of antimony (fig 12) and tin oxides but at generally lower levels than found in the translucent blue glasses. Iron would probably be introduced into the glass as an impurity in the sand and the balance of ferrous to ferric oxides would be important in establishing the final shade of green produced, which in these glasses varied from translucent yellow-green through mid green to pale green. (The actual contribution to the observed colour can be measured using the linear absorption coefficient: Bamford 1977). Blue-green (turquoise) glasses contained higher levels of CuO, as would be expected, and in these instances cupric oxide formed a dominant colorant in the glass (which is also true of cobalt oxide in blue glasses). The emerald green glass sample contained a relatively high lead oxide content of 1.8% when compared to the translucent pale green glass and this different chemical environment for the Cu<sup>2+</sup> ion appears to be the reason for the emerald green rather than a turquoise green colour; both colours contain 2.0% or more of cupric oxide.

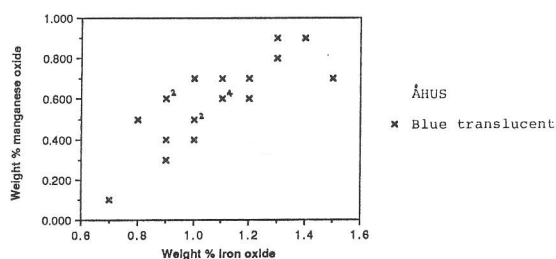


Fig 11. Weight % MgO vs weight %  $\text{Fe}_2\text{O}_3$  in Åhus translucent in Åhus glasses.

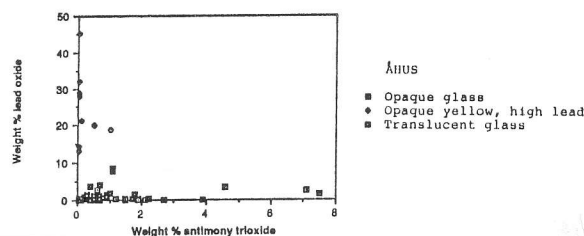


Fig 13. Weight % PbO vs weight %  $\text{Sb}_2\text{O}_3$  in Åhus opaque yellow, other opaques and other translucent glasses.

A single sample of apparently 'black' glass was found to be coloured with a high level of iron oxide (3.4%) and when a small sample was examined in trans-mitted light it was found to be an intense dark brown colour.

### C Opaque glasses

A high proportion of opaque white, green, blue, greeny-blue, grey and yellow glass and translucent glass samples analysed contained antimony oxide (fig 13: in several instances the same data points fall in the same place on the plots) and a smaller number tin oxide (see fig 14). In some opaque glasses antimony and tin were detected at elevated levels when compared to translucent glasses and often present as calcium antimonate (fig 15) or tin oxide crystals (fig 16). In these same opaque glasses a remnant level of antimony will still be in solution even after heat treatment of the glass to develop calcium antimonate crystals out of solution. In opaque glasses tin oxide would probably have been added to the glass as a mineral, and a proportion will have dissolved in the glass, whereas calcium antimonate, which doesn't occur naturally, would have been developed out of solution by heat treatment.

#### Ci Opaque white ( $n=13$ )

All but one of the opaque white glasses analysed were opacified with calcium antimonate crystals and generally a relatively high 'antimony oxide' level was detected in them ranging from 0.8 to 7.5%. The

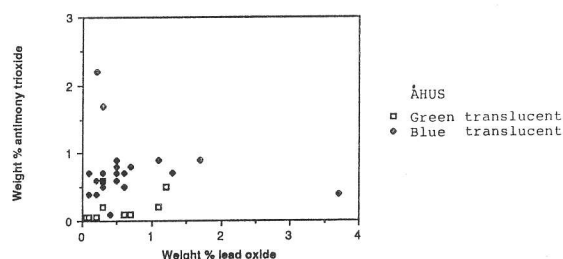


Fig 12. Weight %  $\text{Sb}_2\text{O}_3$  vs weight % PbO translucent green and blue glasses.

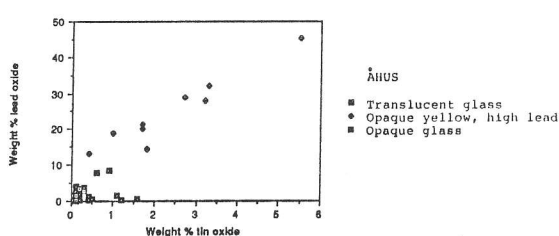


Fig 14. Weight % PbO vs weight %  $\text{SnO}_2$  in Åhus opaque yellow, other opaques and translucent glasses.

variation in level is related to the size and density of crystallites within the 80 micron area of the glass analysed. Although there is quite a wide variation in the level of antimony oxide detected between the samples, most (9/13) contained between 0.8 and 3.9%; three of the remaining samples contained between 6.2% and 7.5%, with a single glass containing 4.6%. A single example of an opaque white glass was found to be opacified with tin oxide. In addition to this range of samples, two opaque white samples taken from monochrome beads contained low levels of antimony trioxide at 0.6% and 0.7% and in a third none was detected. This appeared to indicate that calcium antimonate (and tin oxide) crystals were absent and an alternative explanation for the opacity needed to be sought, such as air bubbles. Although the majority of opaque white glasses were of the LMG composition, two contained high magnesia and low potassium oxide levels diagnostic of Roman opaque white enamels (Henderson, in press (a)).

#### Cii Opaque green ( $n=2$ ); blue ( $n=1$ ); green-blue ( $n=1$ ); grey-blue ( $n=1$ )

Both opaque green samples were opacified with calcium antimonate, the matrix being coloured, as for their translucent equivalents, with iron manganese and copper oxides. One of the samples contained 7.9% PbO. The single opaque blue sample analysed was coloured by cobalt oxide and also opacified with calcium antimonate crystals. An opaque green-blue glass contained an expected 2.5%  $\text{CuO}$ , but only 0.6% antimony trioxide which sug-

gests that a very fine dispersion of opacifying crystals is present. A single opaque grey-blue sample was found to be opacified with calcium antimonate, detected as antimony trioxide (1.9%) and coloured by cobalt oxide, the density of crystals being sufficient to render the glass an opaque grey-blue colour.

### *Ciii Opaque yellow*

Six samples are considered here. Five out of six are opacified by tin oxide in the form of lead-tin oxide crystals ( $\text{PbSnO}_3$ ). These samples contained between 14.6 and 45.4% lead oxide (see fig 14). There was no detectable tin in the remaining sample of opaque yellow glass which contained 0.3% antimony oxide and 1.7% lead oxide (presumably as lead antimonate). The other high lead glasses in fig 14 are single samples of opaque orange and opaque green glasses. The positive correlation between tin oxide and lead oxide in the opaque yellow glass suggests that when the two were introduced into the glass batch they were in the same ratio.

### **D Orange, red and pink glasses**

The single opaque orange glass analysed was found to contain 19.0% lead oxide, 8.5% cuprous oxide and 2.0% ferrous oxide. It is opacified with a dispersion of cuprite crystals of c 1 micron or less in diameter (fig 17).

The most significant features of the opaque red glasses is their relatively low lead and copper oxide levels and the fact that they are a dull browny-red colour. These features are typical of the kind of red glasses which was in use during the 1st century AD and later (Hughes 1972) and not of the sealing-wax red colour. Their composition is quite different from true sealing-wax red glasses which have more in common with the opaque orange glass described above (ie high copper and lead oxides). One of the glasses is of a ruby colour (when seen in reflected light) which is probably due to a sub-micron dispersion of copper metal particles in the glass which are too small to make the glass opaque and not visible under the SEM.

Some of the paler red glasses can be described as pink, though do not have any particular compositional characteristics which would set them apart from the other reddish glass and are often coloured by a sub-micron dispersion of copper or cuprous oxide such as found in the streaked brownish-red tesserae from Åhus (fig 18), where the few copper-rich particles are between c 150 and 250 nanometres

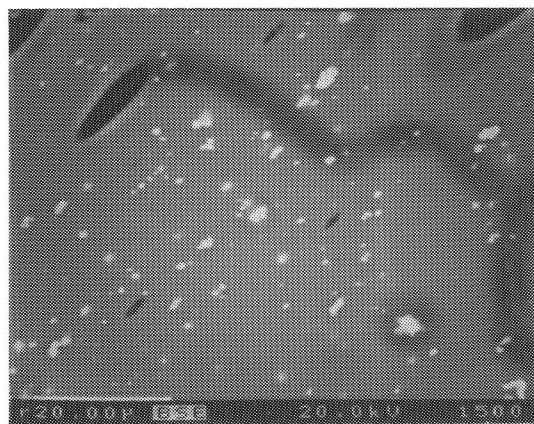


Fig 15. Backscattered scanning-electron micrograph of opaque white glass sample (from a failed opaque white and translucent blue bichrome cable). Note the aligned elongated bubbles, the 'white' calcium antimonate crystals ( $\text{Ca}_2\text{Sb}_2\text{O}_7$ ) and the branching linear zone of weathered glass.

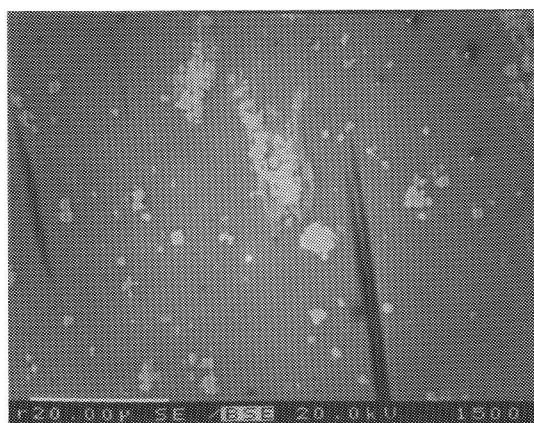


Fig 16. Backscattered scanning-electron micrograph of opaque yellow glass sample in a failed opaque yellow and translucent blue bichrome cable. The "white" conglomerations of crystals are lead stannate ( $\text{PbSnO}_3$ ) which are bathed in a matrix of lead oxide-soda-lime-silica glass. Sections of elongated bubbles aligned in the same direction are to be seen.

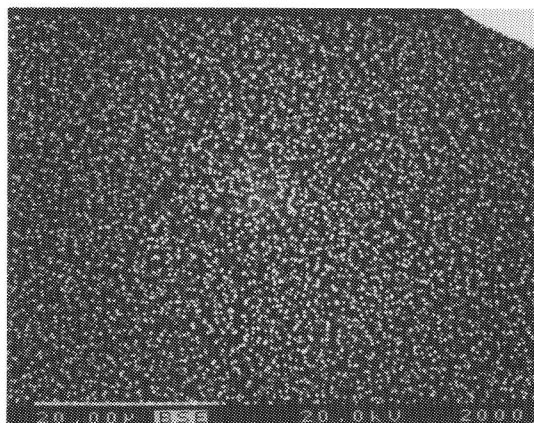


Fig 17. Backscattered scanning-electron micrograph of opaque orange tessera sample. The "white" inclusions are minute cuprite crystals ( $\text{Cu}_2\text{O}$ ) of less than one micron in diameter.

in diameter. Many complex factors affect the final hue of red produced. These include the partial pressure of oxygen and copper, the extent to which the glass is heat treated, the temperatures involved, the furnace atmosphere, the levels of the temperatures involved, the furnace atmosphere, the levels of lead which can aid the solution of copper and the levels of antimony and iron (the latter detected at between 1.2% and 3.4% in red glass) which can act as reducing agents in the glass. The size, shape and distribution of the cuprite crystals in obviously also important in determining the final colour produced. In the case of another red-brown tessera (fig 19) the concentration of iron in the glass is responsible for the overall streaky appearance. Copper-rich particles of c 1 micron in diameter cause the red coloration and their distribution is mainly correlated with the higher iron concentrations (the paler grey colour in fig 19).

## Conclusions

1. Three principle glass compositions have been identified: (i) soda-lime-silica glass, often considered to be of Roman age with low magnesia contents (LMG; (ii) soda-lime-silica glass with higher magnesia levels (HMG) in opaque orange and red glass and (iii) the high lead oxide yellow glasses opacified with lead stannate crystals (" $\text{PbSnO}_3$ "). The opaque yellow glass used at Åhus is very similar in composition to that used in Early Christian Ireland up to 200 years earlier.

2. Much of the translucent LMG is characterised by traces of tin and particularly antimony oxides in solution, and the presence of antimony may suggest that Roman tesserae, which almost invariably contain antimony as part of a crystalline opacifier, were recycled and mixed with cullet, ending up as glass used at Åhus. Roman and Anglo-Saxon translucent vessel glasses do not normally contain the low levels of antimony and tin oxides found in Åhus glass. Analysis of Early Christian Irish translucent glass has, however, shown the existence of traces and minor levels of antimony oxide in translucent blue, green and turquoise glasses. In a plot of weight % antimony trioxide against weight % lead oxide most Åhus green glass forms a tight group, which is distinguishable from the mainly earlier (6<sup>th</sup>-8<sup>th</sup> century) Early Christian glass. The Åhus blue glass forms a cluster which overlaps with a tight grouping formed from Early Christian blue glass compositions, but the Åhus glass generally contains lower antimony trioxide levels. This suggests that the antimony level in the Åhus blue glass may have been slightly diluted

from the original higher levels (2-3% oxide) found in Roman tesserae by the addition of cullet containing negligible antimony such as in Roman vessel glass.

3. The HMG reddish and opaque orange glasses from Åhus have compositional characteristics in

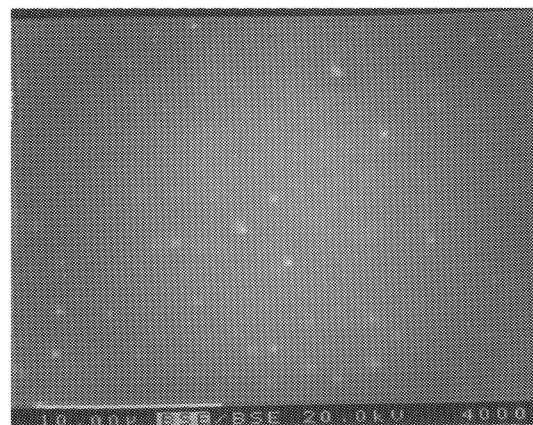


Fig 18. Backscattered scanning electron micrograph of a pale red tessera showing very few visible minute copper crystals. The overall red colour is probably due to a fine distribution of submicron crystals of c 200 nm in diameter and smaller, not seen in the SEM.

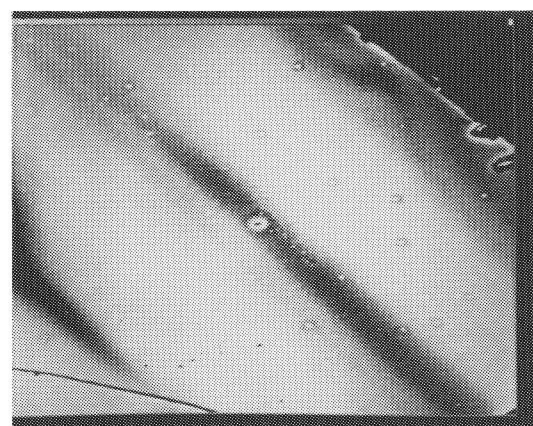


Fig 19. Backscattered scanning electron micrograph of a streaked red-brown tessera. The brighter grey areas are caused by higher concentrations of iron (the length of the figure is 100 microns).

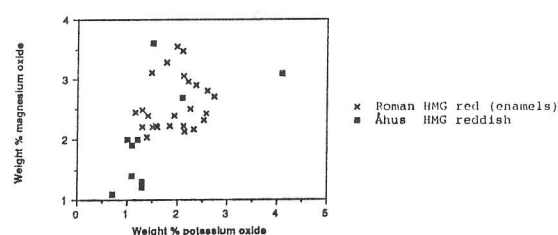


Fig 20. Weight %  $\text{MgO}$  vs weight %  $\text{K}_2\text{O}$  in Åhus HMG reddish glass and Roman HMG red enamels.

common with 1st to 4<sup>th</sup> century AD Roman red enamel and tesserae. Two examples of opaque white glass contained high magnesium but low potassium oxide levels. All these features can again probably be considered diagnostic and are found in Roman-age enamels and tesserae. Because of the availability of data for Roman tesserae and enamels this compositional link strongly suggests the existence of either Roman recycled reddish and opaque white glass at Åhus or glass that has been manufactured in the same tradition (fig 20). The white artefacts at Åhus where this diagnostic composition has been found are tesserae, monochrome rods, multi-coloured rods (millefiori, failed millefiori and a blue and red reticella rod), failed monochrome rods, and polychrome beads. Thus, it seems that a similar stock of opaque (?Roman) white glass was used to make these artefacts. Chemical analysis of the opaque white glass used in the millefiori of the Sutton Hoo gold regalia also provided evidence for the presence of an antimony opacifier/colorant and it was suggested that re-used Roman tesserae was a possible source (Bimson 1983). We now have analytical evidence, based on large data sets, which provides clearer evidence for the re-use of Roman glass in the second half of the first millennium.

4. There is no obvious link between artefact typology and chemical composition, though this will be considered in more detail elsewhere.

5. The artisans at Åhus show high technical skill in handling the glass and control of sources of heat. The artisans had fixed esthetic norms and attitudes to design and choice of colour combinations. Techniques and choice of colour combinations belong to a Western European and ultimately Roman tradition. Undecorated and decorated beads were produced by the same artisans and there is no reason to think that it was more easy to produce the basic form of an undecorated bead than a decorated one. Glass-working is a craft which produces a very rich waste material. Consequently find contexts with only very few finds of production waste must be regarded with caution. Occasional waste products may travel together with finished products.

6. Roman and Byzantine tesserae and Roman scrap glass probably play an important role as components in the glass worked at Åhus. This is evidence of the systematical plunder of Classical sites on the Continent during the early Middle Ages.

7. Minor differences in relation to Insular glass which is also closely related to Roman and Post-roman tradition are however to be noted. This

makes further work with northwest-European Continental material necessary.

8. Although not specifically mentioned above and discussed we may note very close likeness both with regard to technique and the composition of the glass material between Åhus in the Baltic region and Ribe in southwestern Jutland (Denmark). Glass material was probably imported from the same sources in Western and perhaps Southern Europe. Beadmakers at these two sites had the same training and were the same people in fact or maintained very close contacts.

9. The most important finds connected with glass-working in addition to Åhus, Ribe and Paviken, clearly appear on sites which are neither ordinary rural settlements nor big men's manors. Bead-making in the eighth century in parts of Southern Scandinavia was most probably a craft pursued by highly mobile artisans. Only from Gotland we do have observations which suggest a different system. It legitimate to ask whether also a number of other crafts were pursued by itinerant craftsmen at certain sites/trading places.

10. It is not unlikely that the bead-makers and other artisans cooperated with traders or were organised in units comprising both traders and artisans. The legal position of the artisans is not known. All or some of them may have been serfs. The study of the bead making material at Åhus gives us strong arguments for the existence of groups of artisans and traders frequenting the coasts of and possibly some inland routes in Southern Scandinavia in the eighth century.

11. The glass-working was probably conducted by groups of artisans, including at least three or four persons. It is not unrealistic to suggest that this group was composed of a master, two apprentices and one or two helpers.

In conclusion we maintain that the Åhus material provides us with a number of important new insights not only into the organisation, techniques and the physical and chemical properties of the glass material of Late Iron Age artisans in Northern Europe but also into their place in contemporary society.

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