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Prehistoric Glass Technology

– Experiments and Analyses

by TINE GAM

INTRODUCTION

There can be problems of definition when using a craft skill to spread light on aspects of prehistory. Is a "smith's grave" a buried smith or merely someone with the appropriate tools with him in the grave? Can one assume that it was the smith himself who was given the tools for the last journey? The difficulty in interpreting the finds can be that one does not know enough about the materials used. This can mean knowing too little about their chemical and physical behaviour and about the work processes involved. Practical experiments have long been a way getting to understand better both the technology in the narrow sense and the socio-economic context. Glass is a common archaeological find, but it has not often been made the subject of experimental trial. This may be because it is uncommon. The only glass objects known to have been made in 8th-9th century south Scandinavia were beads. Such things as beads, raw glass, trailers, millefiori rods, waste glass, dribbles of melted glass, and even tools have occurred at the seven sites of Ribe, Hedeby, Åhus, Paviken, Helgö, Birka, and Kaupang, leading to various views on the beadmaker's craft (see Callmer 1982 & 1988, Dekówna 1978 & 1990, Frandsen & Jensen 1988a, 1988b, 1988c, Hougen 1969, A. Lundström 1976, 1981, and Näsman 1979).

Probably for most people the techniques of working with glass, whether cold or hot, will be a somewhat recondite subject, and as the making of beads, in the present case by the winding technique, has to the best of my knowledge not been tried experimentally, it seemed a possible way to reach new knowledge of a fascinating subject.

THE SOURCES

A glassmaker's workshop was reconstructed from a combination of archaeological information and present knowledge. The project was to include the production processes themselves in their totality, and the detailed study of tool traces and waste products. Pyrotechnical studies and material analyses are also essential for understanding the technology and for identifying it archaeologically.

The largest part of the material is the glass itself. For information about the actual finds the reader is referred to the literature cited. The finds of glass consist essentially of different types of whole or half beads, by no means all of which can be regarded as locally made. There are also monochrome and polychrome glass threads, raw glass, millefiori rods, waste glass, and lumps of melted glass as mentioned above. Only a few tools have been found. From Paviken there is a metal point 20 cm long with hollow socket and square section. Also fragments of glass with fired clay attached are interpreted as showing that crucibles were used at Paviken (P. Lundström 1981:100). From Paviken there is a metal point 10 cm long with hollow socket and square section. Also fragments of glass bles with green glass (ibid., 17). All the other possible tools are from Ribe. There is a metal rod about 20 cm long with a tapering point and about 10 cm of wooden shaft preserved. There is also a spoon-shaped fragment of antler, a stone with concavity, and at least three furnaces, in the lowest of which was found a little pan of iron (Näsman 1979:131). Four crucible fragments with respectively yellow, red, and green glass on them are not directly connected with any workshop (Näsman, personal communication). In many ways the material from Ribe is the most informative, and it has been the main model for the experiments.

The following description of the present state of research into production methods, the form of the furnaces, the annealing of the beads, the use of crucibles, and the composition of the glass, should not be taken as more than a contribution to the discussion.

PROCESSES

Glass beads can be made by melting fritted glass in a

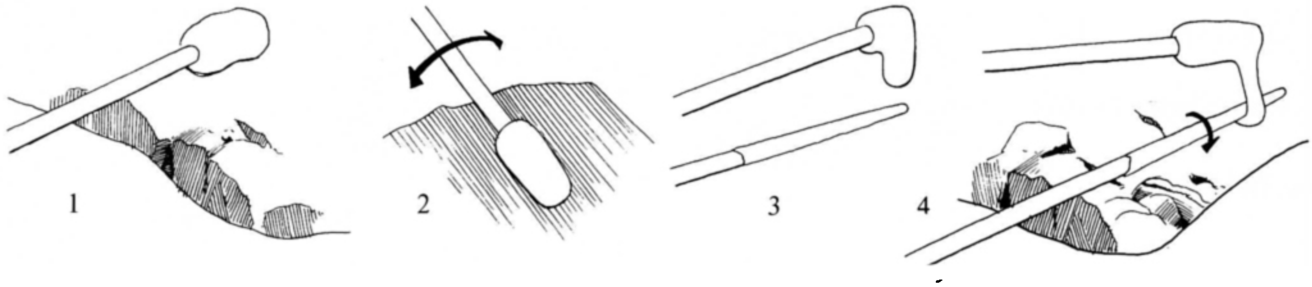

Fig. 1. The hot glass on the pontil being wound around the bead mandrel. Drawing by F.Bau, FHM.

mould, drawing out long tubes which are then broken into suitable pieces, boring a hole through a piece of glass – to mention only some of the possibilities. Here we will describe a technique in which the melted glass is wound around a conical point called a mandrel (see fig. 1). The original lump of glass or the "gather", as it is called among glassmakers, is put on an iron rod, called a pontil. The glass that remains behind when no more beads can be made cannot be re-used because it has fused completely with the pontil. If it is removed, attached oxide scale will be found on the concave side of the glass removed. This was identified in the Ribe material (fig. 2). If monochrome beads are being made the process can in theory be ended here by pushing the bead off the bead mandrel point and letting it cool. Simple beads like this are common, and some were found at Ribe (fig. 3a). The ribs of melon beads were made with a knife. On several melon beads from Ribe the incisions become progressively weaker, which must mean they were made in a single process. The last incisions are therefore made in much colder glass than the first. With a straight-edged knife the bead is given a cylindrical shape, while a semi-circular incision in its edge will give it a round shape. Other ways of shaping are by marvering (rolling) to a *barrel*, *biconical*, or *cylindrical* shape (figs. 3b & 3c). Only the last of these has been tried experimentally. The marver stones used have not so far been recognized among the archaeological finds, and in the experiments a piece of polished granite was used. Any flat surface, for instance part of the tools, could be used. When hot the bead can also be pressed to a polyhedric shape like fig. 3d.

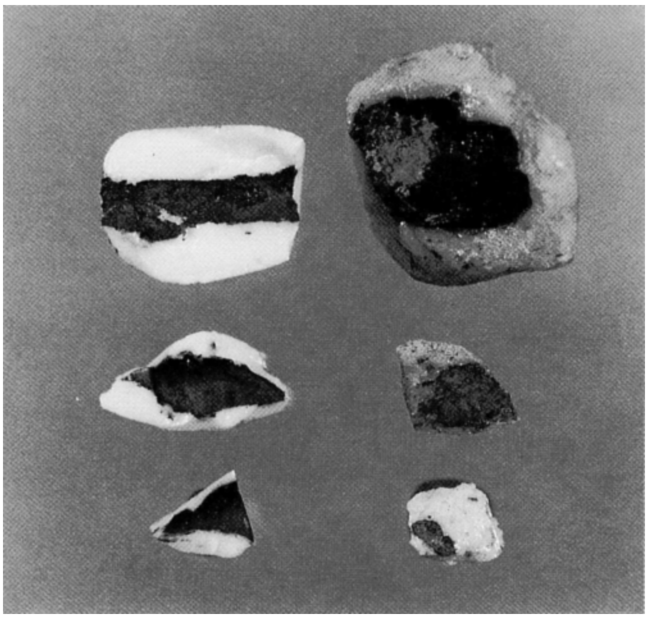

Fig. 2. Pontil glass with attached iron oxide scale from the pontil. Left experimental sample, right from Ribe. Photo H. Strehle, FHM. 2:3

Polychrome beads can be made in many ways, of which we will describe those commonest at Ribe. Some polyhedric beads have been given "eyes" of red or green glass, but the most usual decorative element was threads of white, yellow, or red glass. The threads can be applied singly, or in zig-zag, wavy or straight lines (fig. 3c), or they can be combined in trailer bands and applied to the bead. Finally they can be wound together, making what are called *reticella* beads (fig. 3f).

At Ribe millefiori beads have also been found, and also *half* mosaic beads (fig. 3h), which may show that this technologically quite different type of bead was also being made in south Jutland. The experimental work has not yet included millefiori beads.

Blue is the predominant glass colour in Ribe, followed by green, red, and white. The rest consists of yellow, orange, black, purple, and turquoise glass.

Beads decorated with threads were made using a little plug of glass of the desired colour. When its point was

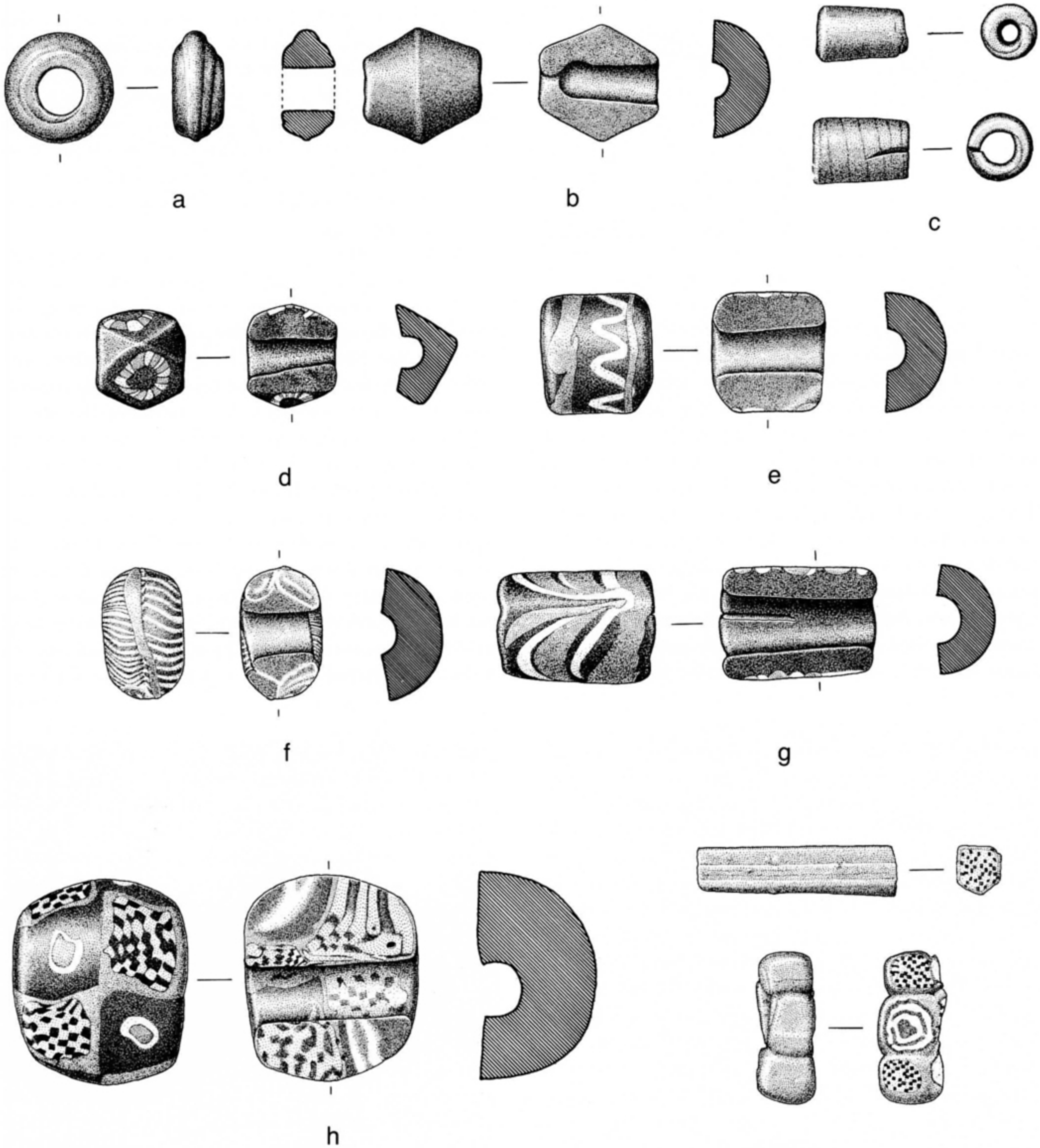

Fig. 3. Beads from Ribe, 2:1. Drawing P.-O. Bohlin, ASR. a, annular blue monochrome bead. b, biconical blue bead. c, cylindrical red bead. d, polyhedric blue bead with "eyes". e, cylindrical blue bead decorated with red and white threads. f, reticella bead. g, cylindrical blue bead with combed pattern of red and white threads. h, millefiori bead, millefiori rod, and flat millefiori piece.

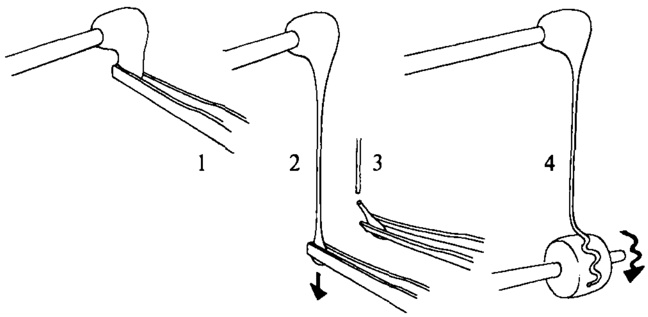

Fig. 4. Tweezers can be used to draw out a thread. Drawing F. Bau, FHM.

heated and melted on to the bead it was only necessary to move the mandrel back and forth to make a zig-zag, or simply turn the mandrel to give a straight trailer. First the tweezer was used to draw out a thread, then the bottom, drop-like piece of glass with the mark of the tweezers had to be nipped off before the thread was reheated and fused on to the bead (fig. 4). This gave a particular waste product, the tweezer mark, which was clearly parallelled in the finds from Ribe (fig. 5), also in having the same characteristic fracture resulting from the cooling effect of the tweezers. But the colours of the pieces with tweezer marks from Ribe do not show unambiguously that they came from the production of beads decorated with threads. If they did, one would expect the usual thread colours to dominate, and these were white, yellow, and red. Instead a majority of the monochrome tweezer marks are blue and green, and they may only show rescue operations when the glass had to be quickly pinched.

When a thread has been freshly wound around a bead it still stands in relief, which can itself be used decoratively. From Ribe there are black and red beads with three yellow threads in relief on them. They can be drawn up as a crest using a pointed tool (fig. 3g), which can also be used to improve the zig-zag of single threads or trailer bands. This is seen when the threads or bands get narrower at the corners of the zig-zags. It can also be seen under the microscope that the air bubbles in the bead itself are elongated or aligned so they follow the angles of the zig-zags. In the experiments a little hook with handle was used, so that the operation could take place as close to the heat as possible. The best result was achieved when the bead with the still plastic threads on it was heated until only the threads were softened. If the bead was heated too much it would be deformed when the threads were pulled. Finds of loose bands of white, yellow, and red threads fused together in parallel, sometimes with a thin layer of blue glass on the back, seem to show how beads with thread band decoration were made. In the experiments the loose threads were put together with a little blue glass on a pontil and then drawn out to a band that could be fused on to the bead (figs. 6 and 7). On the beads from Ribe with band decoration the threads run parallel, but on the experimental beads they turn over at the angles so the back is foremost.

At Ribe we also have *reticella* beads and signs of their manufacture. It can be seen how the reticella threads are put on to a blue bead. Most of them are also decorated with a red thread covering the join of the two reticella threads. Also loose threads, loose reticella trailers, and polychrome pincer marks have been found. The reticella threads consist always of a blue thread in the middle together with thinner white, yellow, or red threads. A number of methods were tried out, but not all aspects of the process are clear. To get the decorative threads on to the blue central thread marvering was first tried. The threads had to be pre-heated and were therefore placed in the pan. Ideally the marvering should be done flat – at an angle of zero degrees. This is hindered by the sides of the pan and was only done for want of anything better. Roesdahl's suggestion that pans were used for rolling must be disputed (Roesdahl 1980:115). A metal sheet would be

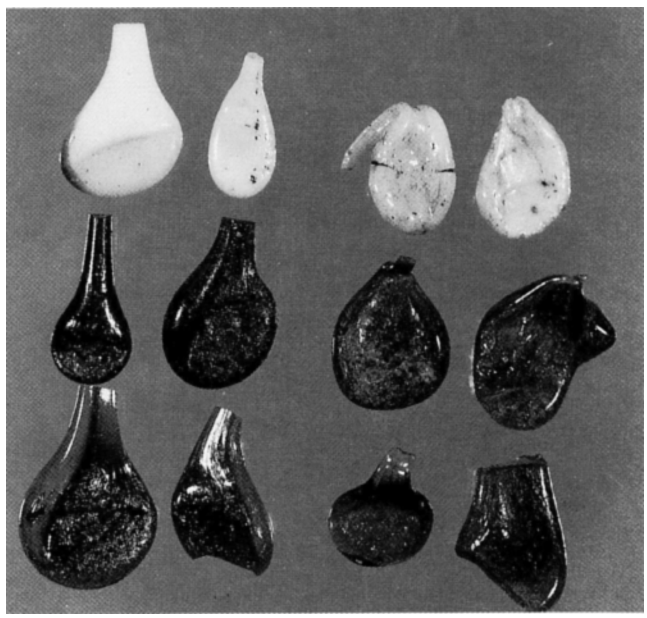

Fig. 5. Glass with impressions of tweezers – tweezer marks. Left, trial piece, right Ribe. Photo H. Strehle, FHM. 3:5.

Fig. 6. Two white and a red thread being joined on blue glass as a thread band. In the pan are two further white and a red thread, and two finished beads being annealed. Photo S. Heinesen, HAF.

Fig. 7. A thread band being put on a bead. Photo S. Heinesen, HAF.

Fig. 8. White threads being rolled on to an end of blue glass. Photo H.S. Rasmussen, HAF.

Fig. 9. White threads being melted directly on to an end of blue glass for reticella beads. Photo S. Heinesen, HAF.

ideal for hot marvering. We may here call attention to a little oval plate with projections at each end found in a pit with "glassworking debris" in Ireland, and was dated to the 6th-9th century (Youngs 1989:204). It may have been used for rolling glass. From Ireland come also a number of iron pans like the one from Ribe, some much more elegant with long thin handle with terminal spirals. These pans are either stray finds or come from sites where glass materials were also found, and are thought to have been used for melting glass (Youngs 1989:204). Although there is no doubt about their connection with the beadmaker's craft, their precise function is open to discussion. There

Fig. 10. White thread being cut with scissors. Photo S. Heinesen, HAF.

Fig. 11. Making reticella thread. The end is rolled forwards while being held and pulled at the point with the tweezers. Photo H.S. Rasmussen, HAF.

Fig. 12. Reticella thread being wound on to a blue bead. Photo S. Heinesen, HAF.

Fig. 13. Reticella thread being cut away with the scissors. Photo S. Heinesen, HAF.

would be no reason to heat the glass to the melting point, when in any case it would fuse with the iron. To fuse pieces of glass together it is enough to heat them to a little over 300°C. It would be quite superfluous first to draw out the threads and then re-heat them for rolling on. Also the glass would be deformed and cooled during the rolling process (fig. 8). Shearing on the threads was therefore tried (figs. 9 and 10). The reticella thread was twisted by holding the point with the tweezers while rolling the thread away from you (fig. 11). On both the original and the replica threads the decoration stands in relief, which it never does on the finished beads. This is the result of the

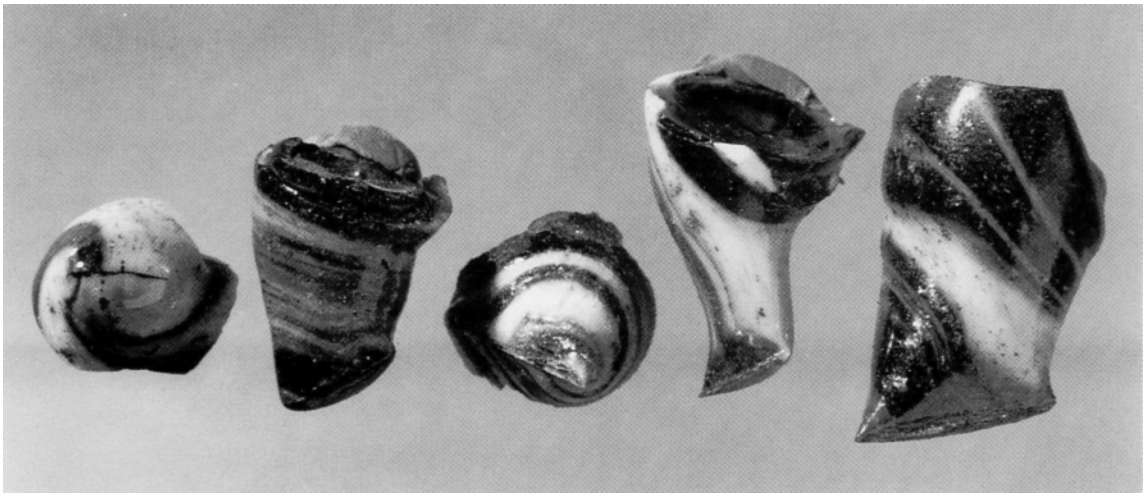

Fig. 14. Ends of reticella glass (the last unusable bit) with cut-marks. Photo S. Heinesen, HAF. 2:3

later heating that is necessary when the threads are to be wound on to the bead. Here also the shears are necessary. If the reticella thread is not cut after one revolution it will have to be wound around several times until it becomes so thin it breaks. There will then be an overlap which interrupts the pattern and is not found on any of the Ribe beads. These have a join of more equal width, because the thickness of the reticella thread is the same all the way around. Such joins occurred in the trials when the shears were used, see figs. 12 and 13. There are still disagreements between the replicates and the originals, as reticella threads with cutting marks have not yet been identified among the latter (cf. fig. 14), on the other hand the archaeological finds are only a small fraction of the original waste products. It was also a problem to make the threads run across instead of along the beads, but it is hard to say whether this was due to lack of experience or to the difference between the original glass and the glass used in the trials.

THE FURNACE

This was the centrepiece of the workshop, and the study of furnaces and pyrotechnology is of central importance. The archaeological evidence is rather weak on this point. The hearths found in Kunstmuseets Have in Ribe were described as concentrations 25–30 × 50–60 cm in size of reddened clay, charcoal, and glass (Näsman 1979:125). For the trials a simple, open construction of stones the size of a fist was used, plastered with sandy clay. The dimensions were the same as in Ribe and the depth was ca. 15 cm. All had the blow-hole at floor level and either manual or electric bellows. Deciduous charcoal was used as fuel. It was easy to reach a temperature of 1000–1100° C in the hottest part of the furnace – even 1400°C – but was hard to hold the glass there without getting it contaminated with charcoal powder and ashes. Heat loss is considerable in an open hearth, and in an attempt to reduce this a board was placed over its back. With this the maximum heat was shifted to directly *above* the charcoal. It was on the whole difficult to avoid contaminating the glass. Although some of the beads from Ribe show this too, the majority have a smooth and shiny surface. Contamination can be reduced by increasing the distance between the charcoal and the glass, i.e. by using a taller and more enclosed construction in which the heat gathers at the top. In the present century a kind of shaft kiln was used to make beads and rings at Bida in Nigeria. Up to five men worked around the hole at the top. The kiln was about half a meter high (Dubin 1987:123, Gardi 1974:87). In Turkey they still wind beads using a kiln with two chambers and built-in "pockets" for annealing the beads (Küükerman 1988).

There is however one thing that argues against the theory of the shallow hearth. In all the experimental hearths the floor close to the blow-hole and the sides near it became strongly vitrified (fig. 15). As this was not found in the Ribe hearths one can perhaps suppose that the blow-hole, and with it the hottest part of the hearth, was

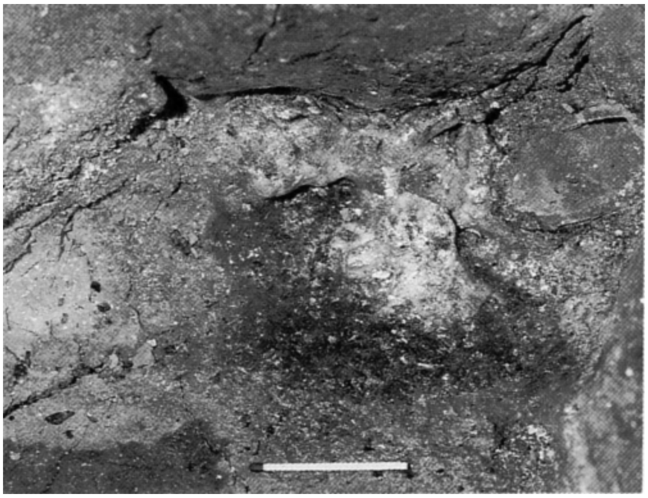

Fig. 15. The hearth showing blow-hole and strongly vitrified bottom and sides. Photo H.S. Rasmussen, HAF.

located a little above floor level, which would be a further argument in favour of a much taller construction. Unfortunately there seemed to be no sign of either cover or sides (Näsman 1979:125), but it is a question whether this is to be expected at a site that has so clearly been cleared and levelled several times.

ANNEALING

After being heated to over 500°C glass must be cooled down uniformly. Otherwise there may be internal stresses in the glass and fractures can occur. Air bubbles hinder an even cooling, and can be especially harmful in small objects like beads. When crucibles are used the cause of the bubbles is that air is caught in the frit. The same can happen if cullet is used. Air can also be caught in the process of winding. It is therefore difficult to evaluate precisely the methods of annealing tried out.

In the first a copy of the iron pan was placed on the edge of the hearth above the blow-hole, where the temperature was c. 300–400°C. After being finished the beads were placed on it, using an annealing tongs based on the one piece of antler. When the fire had been brought up, the pan with the beads was placed directly in the hearth, bringing the pan's temperature up to c. 500°C, cooling slowly as the fire died down. This form of annealing seems at first to be effective, but being on the rim of the hearth gave too much variation of temperature, and as an alternative it was tried annealing the beads in ash and sand. Here ash was preferable, as sand gave too much resistance when the beads were being inserted. They lay only in the surface layer and far more of them broke in the sand than in the ashes. First a fixed "annealing corner" was tried in the form of a little clay pocket in the hearth. As it was beside the blow-hole it was impossible to regulate, and the temperature was too high in its lower part. This was shown not only by the pyrometer, but also by the beads. The lower down they had been, the more ash had fused on to them (fig. 16). The best method was a movable container in the form of a clay pot filled with ash placed in the hearth opposite to the blow-hole.

CRUCIBLES

Despite the limitations of the archaeological evidence, descriptions of bead- making in Iron Age and Viking Scandinavia nearly always mention the use of crucibles for melting the glass (i.a. Callmer 1982, Jørgensen 1982, A. Lundström 1976, P. Lundström 1981, Näsman 1979). After experimenting with crucibles I will here propose a number of practical arguments against their use. The consumption of both glass and fuel would be greater. Energy would be needed not only to melt the glass, but also to heat the crucibles. After use some glass will always remain behind in the crucibles – glass that can never be wound on to a pontil. The proportion of the glass that can actually be used seems therefore unnecessarily low, considering the supply of raw materials and the value of glass. Not only would there be a layer of glass inside the crucibles, but also the outside gets glazed as a result of the high temperature. This means they are easily preserved, and if used they should be found whenever other remains from glass- making are found. Crucibles are *not* necessary to make a gather – which is the first stage in the process of

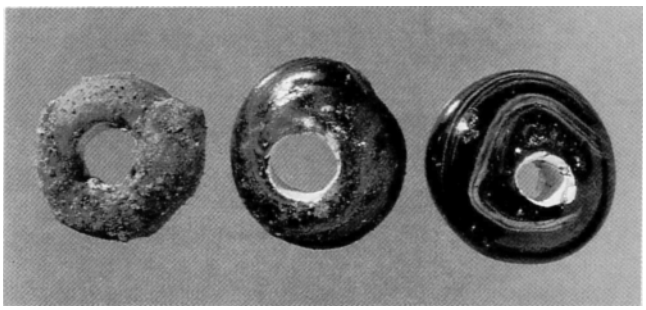

Fig. 16. Annealing of beads in hot ashes. At temperatures below 500° the ash does not attach itself to the beads.

winding beads. When the pieces of glass are being pre-heated, in this case on the pan, which is now being used for something different from annealing, pieces of increasing size can be melted directly on to the pontil, making the use of crucibles unnecessary. This is not saying that crucibles were never used in the production of glass beads, but it emphasizes how important it is to examine both the crucibles and the glass to determine whether the vitrification was deliberate or only accidental, and to compare the elemental composition with that of other locally produced glass.

But one question is whether glass was being melted or even only heated in crucibles, and another is whether it was being made from original materials. At Dunmisk in western Ireland there have been found a number of crucible fragments with glass attached, and further waste from glass working (Henderson 1988:145). One of the pieces was analysed using SEM and EPMA, and Henderson was of the opinion that half-fuzed raw materials could be found in the glass mass, which was interpreted as showing that the glass in the crucible was from the deliberate production of glass. From this one might be able to envisage different types of glass-making, in which the use of raw glass, tesserae, and perhaps cullet occurred alongside actually making glass. This may have happened in the context of certain centres, perhaps monasteries. Henderson points out that there were monasteries near Dunmisk and Armagh (Henderson 1988:146).

It is also worth while to examine the elemental composition of the crucibles and see if it is possible to determine whether it was local or imported raw materials that were used. Freestone and Tite have examined the composition of material from crucibles and hearths and found that refined local materials were chiefly used (Freestone & Tite, 1986, 56), but the possibility that clay from northern Germany or Holland was used in Ribe to make the moulds for bronze brooches cannot be excluded (Brinch Madsen 1984:32). Finally it may again be stressed that crucibles do not *have* to be used for making glass beads by winding.

GLASS

Glass contains three main components – a glass former, a flux, and a stabilizer. The first is a mineral silicate, usually quartz sand. Pure sand has a melting point of over 1700°C, but when the oxide of the base sodium or potassium is added as a flux, the melting point can be reduced to c. 1300°C (Frank 1982:10). As the product of the reaction between these substances is water soluble, calcium is added. Metal oxides can under different firing conditions be used to alter the colour or opaqueness the glass. The quantity and character of the flux will determine for how long the glass can be shaped before it has to be re-heated. Lead, which can function both as flux and stabilizer, makes the glass "longer" (Schlüter 1979:397). So far only a few glass analyses from Hedeby and Ribe have been published, and they suggest that the common use of a soda glass with 10–15% Na but only 0.5–1.5% K (Dekówna 1990, Henderson & Warren 1983). This is characteristic of most glass until the Middle Ages, when it was replaced by a glass with more potassium. Soda glass is relatively "short", and therefore different to work with than the glass used for most of the trials. This was modern glass, and therefore purer, and it also had a much higher content of lead and potassium (Gam 1989). In some respects its tolerance was greater than that of the original glass. Unfortunately it was not either practical nor economically possible to make glass like the original one for use in the trials, and it is open to question whether it ever will be possible. Analysis gives some indication of the raw materials in glass, but exact determination of the raw materials and their origin is unattainable.

The latest part of the experiments was focused especially at the types of glass, for we succeeded in obtaining a soda glass that agreed with the prehistoric one at least as far as the flux was concerned. The first results confirmed expectations that it was a "shorter" glass, and its tolerance of annealing temperatures was far less. This glass could not have been annealed so well on the pan, though of course it is difficult to know which factors are the most important. One should always bear in mind the effects of different kinds of glass when discussing early manufacturing methods.

Nor has it been possible to find experimentally whether there was any reason behind the use of particular colours at Ribe. When red, white, and yellow are often used to decorate blue beads but not the other way around, is it only a matter of fashion, or are there good technological reasons?

THE FUTURE OF EXPERIMENTAL STUDIES

Experimental work can never be seen as finished, but there is already ground for revising the way the craft has been described theoretically. The workshop is equipped with much more than "a hearth, a crucible, a tongs, and a metal rod" (P. Lundström 1981: 100). Separator, marver stone, hearth tongs, bellows, a holder for pontils and bead mandrels, something to pulverize with, containers, and people to help, are seldom mentioned in the archaeological literature, but were an important part of the trials. Descriptions of processes also become much fuller when based on methods that have been tried out. The study of the work processes is not an end in itself, but is a necessary precondition for the comparison of waste products and gives clues to the methods followed. It is therefore essential to the correct identification of archaeological finds. Interest is often concentrated on the question whether production actually took place at the site, and unless the workshop area itself is found, containing the hearth or kiln, judgement can only be based on the other material. Glass is often only treated quantitatively. It is only asked what is present. A more differentiated approach is needed, for some of the finds may have circulated as trade goods, which means that their mere presence does not show that production was carried out. This applies in general to any pure glass suitable for melting down – i.e. monochrome threads and tweezer marks, lumps and dribbles, and raw glass. On the other hand polychrome threads and pincer marks, pontil residues, broken beads, and pieces that have been contaminated in one way or another cannot be recycled. This can make them an important source of information, for there is no reason to remove them from the production area. The Scandinavian material comes from sites where there are also indications of trade and of the performance of other crafts. The question of the tools has not been fully solved, but we now know more after the trials. The precise design of the tweezers, for example, is not of great importance, as the tool used in the trials left the same marks in the glass as the original one did. Similarly the exact form of the mandrels is of secondary importance, while the basing of the annealing tongs on the spoon-shaped piece of antler is so slender that there would be no point in looking for that tool and the trials have only shown a *possible* use. As for assistants, at least one is necessary for blowing the bellows. So far it has been impossible to make reticella beads without a helper, and if shears were used there was probably always a need for an assistant. Other types of beads, for instance millefiori, are likely also to require a number of assistants. The living reconstruction of the workshop environment showed the obvious advantage of involving a number of people in the work processes. The trials thus provide a basis for estimating the craft's social organization and socio-economic integration.

By no means all sides of the beadmaker's craft have been illuminated. This applies to pyrotechnological aspects and to types of glass, but also processes involved in making the individual types of bead still need to be tested. There are also more general aspects of glass technology, where questions involved in bead- making have a wider application in glass- blowing. Why is a beadmaker's workshop in Ribe the earliest indication of glass working in Scandinavia, when workshops producing blown glass existed in a wide belt over the continent from the British Isles to the Black Sea? Part of the answer is no doubt to be sought in social relations, both at the internal national level, and in contacts between the larger regional areas. These are all stimulating perspectives in a fascinating subject.

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NOTES

1. The experimental work began in 1988 at Moesgård, Institute of Prehistoric Archaeology and at Lejre Historical-Archaeological Experimental Centre.
2. Once the temperature exceeded the pyrometer's maximum limit of 1370°.
3. Glass from Friedrich & Scheibler GmbH – Kugler Colors.
4. Glass made by Mark Taylor based on glass from the 2nd-3rd century (Forbes 1966).

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