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THE GLASS BEADS OF RIBE – EVIDENCE OF LOCAL GLASS BEAD MAKING AND LONG-DISTANCE TRADE

The city of Ribe was established just after AD 700 and was from the very beginning a well organised trade and craft centre with a marketplace situated to the north of the Ribe River, closely connected with the North Sea trade. The glass bead makers were among the first craftsmen to establish workshops in Ribe, and the marketplace contains the best-preserved evidence of early medieval glass bead making in Northern Europe. The marketplace functioned with one or more seasonal markets every year until the end of the 8th century. The marketplace then changed in character, as some individual plots revealed evidence of a permanent settlement, indicating that from this time there seems to be a continuous presence of craftsmen and traders. Around AD 850 the archaeological layers on the marketplace come to an end, and finds and features dating to the following 150 years are almost absent[1].

THE RIBE BEADS

The glass bead material is unique in terms of the large number of both imported and locally made beads. The finds consist of intact beads, fragments and semi-finished beads, as well as production waste, raw materials, bead making tools and remains of furnaces and workshops related to the domestic production of glass beads[2]. There are many finds from the 8th century that can be attributed to local manufacturing of glass beads, but also from the 9th century indicating continuing glass bead production on the site although on a minor scale. The contexts of the finds from the excavations at Ribe allowed a classification of the archaeological material into phases, subsequently dated very precisely[3].

Nearly 25 000 pieces of glass have been excavated ranging in date from circa AD 705 to 850. In addition to 5 925 whole and fragmented glass beads, 4 700 pieces of raw glass mostly in the form of smaller blocks, lumps or splinters, 6 316 pieces of bead making waste including semi-manufactured components like mono- and polychrome glass rods, 4 583 pieces of glass tesserae and 3 325 fragments of hollow glass have been found[4]. Based on the uncovered evidence, the glass bead making was entirely based on reusing and melting imported raw glass, tesserae and cullet.

Beads made locally in Ribe

In the first years the beadmakers were exclusively producing wound glass beads. These were predominantly monochrome, often transparent blue or opaque white, but included other colours as well as polychrome beads. Around AD 720 the bead material changed character and in addition to a large production of monochrome glass beads in different colours, cobalt-blue beads, often decorated with opaque red and white trails (**fig. 1b**, 5M74DxD5887) or prefabricated red, white and occasionally yellow-striped ribbon rods (**fig. 1a,** 5M74DxD5700) occur in large numbers. Also the so-called reticella beads with multicoloured filigree rods in different variations were produced. In addition, the bead makers at Ribe used pre-formed

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5M74DxD5700. Wound cylindrical blue bead with polychrome zig-zag decoration. Cobalt-blue is mixed Antique/Late Antique Egyptian natron glass, white is high-magnesia Egyptian and red is Egyptian plant ash glass. – 11 mm × 8 mm.

5M74DxD5887. Wound cylindrical blue bead with white zig-zag decoration and framed with red threads. Cobalt-blue is mixed Late Antique Egyptian natron glass, red is Egyptian plant ash glass, white is Antique Levantine glass. – 11 mm × 8 mm.

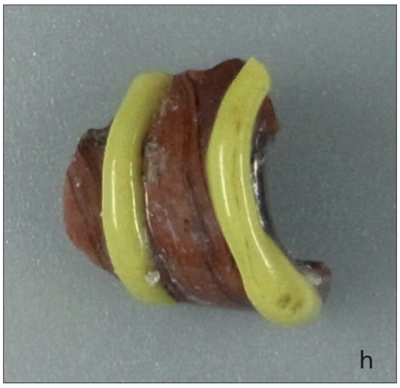
5M74DxD6361. Melon shaped wound and tooled glass bead. Cobalt-blue is mixed Late Antique Egyptian natron glass. – 9 mm × 8 mm.

ASR9x185. Blue cornerless cube bead with red and yellow eye decoration. Cobalt-blue is mixed Late Antique natron glass, red is Late Antique natron glass. – 11 mm × 7 mm.

ASR9x402 263. Wound blue bead with applied mosaic eyes. Cobalt-blue is Antique Levantine glass, white is Antique Egyptian natron glass, red is mostly Late Antique Egyptian natron glass. – 10 mm × 10 mm.

5M74DxD4699. Wound blue bead with red and yellow thread decoration and white dots. Cobalt-blue, yellow and white are Late Antique Egyptian glass, red is Late Antique Levantine glass. – 13 mm × 8 mm.

ASR9x329. Mosaic bead made from fused mosaic chips. Cobalt-blue, green and red glass are mainly Late Antique Egyptian natron glass. – 12 mm × 9 mm.



ASR9x392 02. Fragment of wasp bead. Red and yellow are Late Antique Egyptian natron glass, mostly tin opacifier. – 7 mm × 7 mm.

ASR9x392 08. Wasp bead. Black and yellow are mixed Late Antique Egyptian glass, mostly tin opacifier. – 8 mm × 7 mm.

Fig. 1 Locally manufactured Ribe beads made from recycled Antique and Late Antique natron and plant ash glass. Most glasses mixed but predominant types indicated. – (Photos T. Sode and J. Lankton).

mosaic canes with floral and chequer-board designs to make mosaic beads (**fig. 1g**, ASR9x329; **fig. 3g-i**, 4M75xD13318, 4M75xD13336, 5M74DxD5758). It is likely that both types of mosaic canes were produced locally or regionally, with excellent evidence found on Bornholm[5]. These characteristic glass beads were produced up to around AD 760, and the period from AD 720 to 760 has been called the »Blue Period« by J. Callmer[6]. Just after the mid-8th century new types of beads emerge. Monochrome wound cylindrical beads, generally a little smaller in size and often in opaque red brown or green colours occur. The so-called wasp beads appeared simultaneously. The typical wasp bead is a black cylindrical bead with most often three parallel applied opaque yellow glass threads (**fig. 1i**, ASR9x392 08). The wasp beads are also found in variations with opaque red brown, transparent green or blue glass with variations of applied yellow thread decoration. Typical wound beads decorated with coloured trails or mosaic chips as well as characteristic »wasp beads« illustrate recycled mosaic tesserae and unworked glass to be used as raw material for bead making, along with examples of glass working debris including drawn canes, some polychrome, and chips of glass cut from pre-formed mosaic rods. Major glass compositional types, as discussed below, are indicated for each sample.

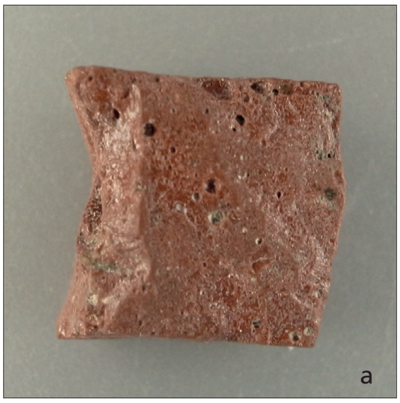
Imported Near-Eastern glass beads

Mosaic glass beads

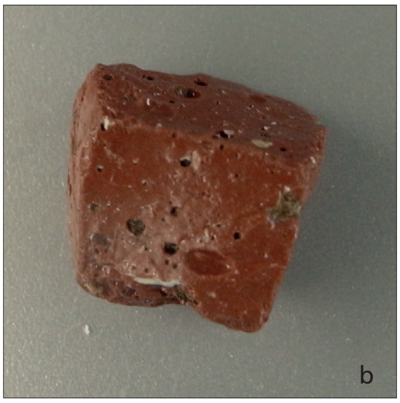
In the last third of the 8th century the bead material totally changed character and the next more than 50 years were dominated by beads imported from the Near East[7]. A new type of mosaic eye bead appears, mostly cylindrical and made from segments of prefabricated mosaic rods with patterns in various eye motifs or circular designs. The bead is manufactured by first fusing the mosaic motifs together, and then folding the red-hot mosaic pad around a bead mandrel. The join where the folded glass is fused together is clearly visible (**fig. 4a**, ASR9x491 200064002). The cylindrical beads are finally decorated with a multicoloured striped rod, made mostly in white/red/yellow glass, wrapped and marvered around the ends of the bead. The Near Eastern glass mosaic eye beads are carefully described by R. Andrae[8] and they belong to J. Callmer's group Ga[9]. Also found at the market place are globular or oval mosaic eye beads made by transversely piercing a heated slice from a mosaic rod using a metal tool; diagnostic for these beads is that the perforation where the rod entered is always larger than the perforation on the exit side, and the circular outline of the original cane is distorted because the glass was pushed in on one side and pushed out on the other (**fig. 4**, ASR9x491 200063816).

Segmented metal foil beads

Another new type are segmented metal foil beads (**fig. 5a-b**, ASR9x113 59, ASR9x105 01). These have been found at late 8th century sites all over Northern Europe. In contrast to the earlier gold foil beads of the Hellenistic and Roman Iron Age, only silver foil is used in the production of these later metal foil glass beads[10]. The use of transparent amber-brown glass for the outer layer gives the impression of gold beads, while using a transparent colourless glass makes the beads resemble silver beads. A further type utilized a transparent blue or greenish outer glass to create metallic beads in colours not found in nature (**fig. 5c**, ASR9x392 200061613). Also segmented opaque yellow beads occur, with one example from Ribe consisting of five joined segments. The majority of the segmented metal foil glass beads found in Ribe has an amber-



4M75xD08084. Red opaque Antique/Late Antique Egyptian natron glass. – 11 mm × 11 mm.

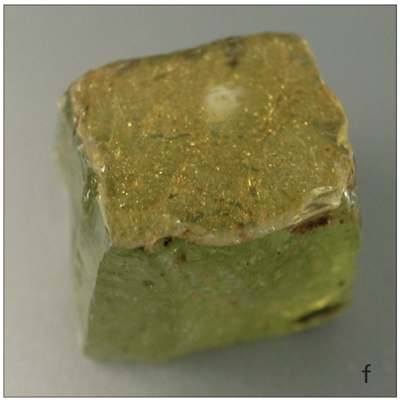


ASR9x325 03. Red opaque Antique/Late Antique Egyptian plant ash glass. – 8 mm × 7 mm.

ASR9x194. High-copper orange Antique/Late Antique Egyptian plant ash glass. – 11 mm × 10 mm.

4M75x9979 01. Yellow opaque Antique Levantine natron glass, antimony opacifier. – 11 mm × 11 mm.

4M75xD12406. Green Antique Levantine natron glass. – 9 mm × 8 mm.



ASR9x227 05. Colourless Late Antique Egyptian HIMT natron glass with gold foil. – 8 mm × 9 mm.

ASR9x227 08. White Antique mixed natron glass, antimony opacifier. – 11 mm × 10 mm.

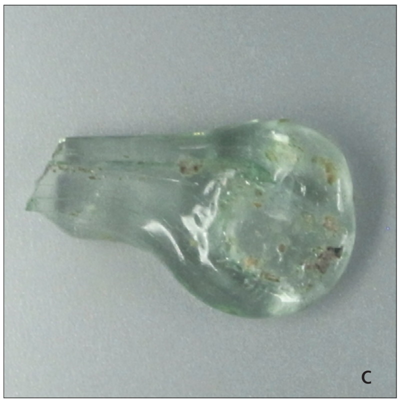
4M75xD10052. Cobalt-blue Late Antique Egyptian natron glass, antimony opacifier. – 9 mm × 6 mm.

ASR9x227 01. Cobalt-blue mixed Antique Levantine natron glass. – 13 mm × 12 mm.

Fig. 2 Mosaic tesserae found on the marketplace in Ribe. Antique and Late Antique natron and plant ash glasses from Egypt and the Levantine coast. – (Photos T. Sode and J. Lankton).

ASR9x286 04. Cobalt-blue Late Antique Egyptian natron glass chunk. – 19 mm × 15 mm.

5M74DxD6002. Cobalt-blue mixed Late Antique Egyptian natron glass trail with toolmark. – 8 mm × 6 mm plus tail.

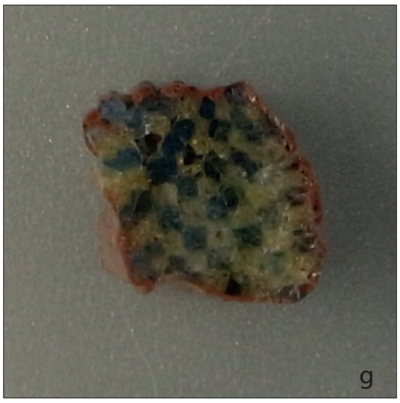


5M74DxD4043. Colourless Late Antique/ mixed Egyptian glass trail with toolmark. – 15 mm × 9 mm.

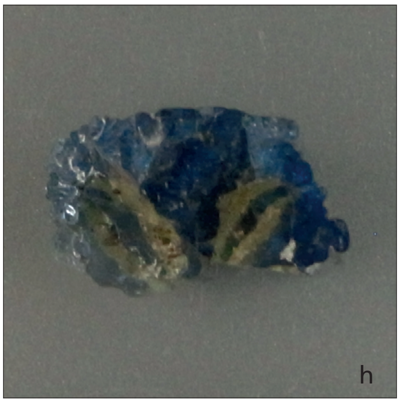
4M75xD9616. Green Late Antique Egyptian natron glass, mixed opacifier. – 15 mm × 11 mm.

4M75xD13416. Cobalt-blue mixed Late Antique Egyptian natron- and white high-magnesia Egyptian glass. – 16 mm × 5 mm.

5M74DxD5596. Red and white Late Antique Egyptian natron glass, antimony opacifier. – 15 mm × 7 mm.



4M75xD13318. Yellow and dark cobalt-blue mixed Late Antique Egyptian natron glass, red Egyptian plant ash glass. – 6 mm × 5 mm.



4M75xD13336. Cobalt-blue and yellow mixed Late Antique Egyptian natron glass, antimony and tin opacifiers. – 8 mm × 5 mm.

5M75DxD5758. Cobalt-blue and yellow Antique Egyptian natron glass, red Egyptian plant ash glass. – 6 mm × 4 mm.

Fig. 3 Raw glass and beadmaking debris, including mosaic cane fragments, as evidence for local glass beadmaking in Ribe. Most glasses at least partially mixed but predominant types indicated. – (Photos T. Sode and J. Lankton).

ASR9x491 200064002. Fused and folded cylindrical mosaic glass bead; Mesopotamian Islamic plant ash glass. – 16.5 mm × 7.5 mm.

ASR9x200063816. Mosaic eye bead made by piercing a section of mosaic cane; Mesopotamian Islamic plant ash glass. – 14.0 mm × 5.5 mm.

ASR9x21 A11. Wound bead with applied mosaic eyes and white crossed trails; wood-ash potash-lime glass. – 12 mm × 11 mm.

ASR9x374 200061907. Translucent green facetted tubular bead; lead-silica glass. – 8 mm × 5 mm.

5M74Dx5886. End view. Barrel-shaped bead with flat ends made from glass chunks fused around a mandrel; high-alumina mixed-alkali glass. – 10 mm × 6 mm.

5M74Dx5886. Side view. – 10 mm × 6 mm.

5M74Dx6043. End view. Barrel-shaped bead with flat ends slightly more homogeneous than 5M74Dx5886; high-alumina mixed-alkali glass. – 10 mm × 7 mm.

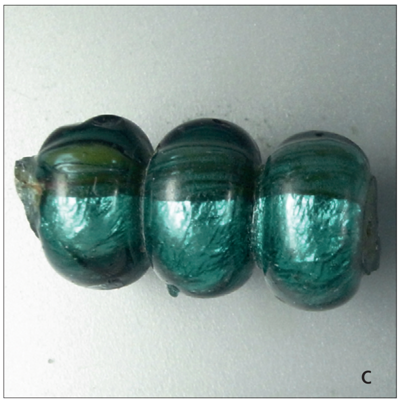
5M74Dx6043. Side view. – 10 mm × 7 mm.

ASR9x165. Wound yellow bead with applied sections of mosaic cane. Yellow and white are Mesopotamian Islamic plant ash glass, red is Egypt 2 natron glass. – 8 mm × 7 mm.

Fig. 4 Mosaic and monochrome beads made from a variety of glass types as indicated. – (Photos T. Sode and J. Lankton).

ASR9x113 59. Three segment silver foil bead with amber-brown outer glass. – 17 mm × 7 mm.

ASR9x105 01. Two segment silver foil bead with colourless outer glass. – 10 mm × 6 mm.



ASR9x392 200061613. Three segment silver foil glass with green outer glass. – 17 mm × 7 mm.

ASR9. Four segment monochrome cobalt-blue bead.

ASR9x374 02. Interior of segmented silver foil bead with amber-brown outer glass. – 10 mm × 7 mm.

ASR9x296 19104. Small monochrome pale blue drawn bead. – D. 6 mm.

ASR1357x50. Cobalt-blue small monochrome drawn bead. – D. 6 mm.

ASR1357x205 03. Opaque green small monochrome drawn bead, tin opacifier. – D. 4 mm.

4M75xD11495. Two yellow small monochrome drawn beads fused together. – L. 10 mm.

Fig. 5 Segmented metal foil beads, segmented monochrome and small monochrome drawn beads. All made from Mesopotamian Islamic plant ash glass. – (Photos T. Sode and J. Lankton).

brown outer glass. Most consist of only one segment, although beads with two, three or more segments have been found, including one example with seven. The metal foil beads from Ribe are found in different forms and sizes. The individual segments can be spherical, oval, ring-shaped or cylindrical. The diameter is in most cases between 4-6 mm, but can vary between 2.5 and 11 mm. From Callmer's latest research on the segmented glass beads from the Black Earth on Birka, he could distinguish that metal foil beads with brown, blue or greenish blue outer layers, as well as the beads with larger segments and beads with only one or two segments were dominating in the earliest finds [11]. This corresponds very well with the finds from Ribe, and with Lundström's investigations on the Birka beads [12]. The bead material from Ribe also includes four so-called collared beads, three with a colourless outer glass and one with an amber-brown outer glass. Collared beads are composed of an oval central segment with disc-shaped segments on both sides.

The segmented metal foil glass beads seem to have been manufactured by pre-fabricating an inner core and an outer tube separately. A piece of silver foil was rolled around the inner core, which thereafter is placed inside the outer tube. The very distinct straight edges of the silver foil indicate that the foil was placed between the two layers of glass in cold conditions. The drawn glass of the inner core was filled with elongated bubbles parallel to the perforation, making the glass greyish with a somewhat milky appearance (**fig. 5**, ASR9×374 02). The outer glass was made as a thin walled transparent glass tube, likewise with long drawn oval shaped air bubbles. The compounded glass tubes were mounted on an iron mandrel and then warmed and rolled over a grooved stone form. After cooling, the individual segments were broken off as separate single beads or as beads composed with a number of segments; the broken ends can often be recognized by the sharp edge around the bead perforation. During the manufacturing process the silver foil is often burnt to the outer glass, which is possibly the reason why the metal is often missing where the outer glass has broken off.

Stone moulds used in the production of segmented glass beads were recovered from the excavation of a glass bead workshop dated to between the 4th and the early 7th century in Kom el Dikka in Alexandria [13]. Kom el Dikka is somewhat earlier than the bead material from Ribe, but the find clearly illustrates how segmented glass beads may have been produced. One bead was found burnt onto an iron wire that had been used when heating and forming the segmented glass beads on the grooved stone forms. The presence of the iron wire explains the internal structure clearly seen on the broken beads, where the otherwise uniform bead perforation exhibits an expansion in diameter in the middle of each segment. Although, to our knowledge, similar stone moulds have not been found in Mesopotamia, where the metal foil beads from Ribe were made, adoption of similar Egyptian technology throughout the Abbasid Caliphate seems likely.

Small and large monochrome drawn glass beads

A third group of imported glass beads that occur in large numbers in Ribe as well as other parts of southern Scandinavia, are monochrome drawn glass beads cut from tubes (**fig. 5f-h**, ASR9x296 19104, ASR1357x50, ASR1357x205 03). These beads are found in Ribe from around AD 780, and in great numbers elsewhere, especially in Early Viking Age contexts. There are two general types: small with an outer diameter between 2 and 6 mm and larger with a diameter between 7 and 12 mm, and together they make up about half of the bead material from the earliest layers in the Black Earth area in Birka, just as they appear commonly in the grave finds from Birka [14]. From Haithabu, 2 556 pieces, most small, have been recovered, making up 35 % of the bead material. In the harbour area there was a find with 598 pieces of mainly blue tubular drawn beads along with seven silver coins dating to around AD 825, as well as a necklace with 248 small, yellow drawn beads[15]. While there is some overlap between the two size groups, it is clear that at Ribe the majority of the monochrome drawn glass beads are small.

Because the monochrome drawn glass beads were cut from prefabricated, thick-walled glass tubes, the bead perforation is relatively small and cylindrical. There is a clear longitudinal structure in the glass, parallel to the perforation. The beads are often found in blue, turquoise, yellow, green and white. While the original sharp broken ends of these drawn glass beads have usually been rounded by re-heating, in the archaeological material it is possible to see that different methods have been used. The smallest beads were probably rounded by placing the cut cylindrical glass tube fragments in a bowl together with ash. The bowl was then placed in a furnace or hearth where the sharp edges will naturally round because of the high surface tension of hot glass. The ash prevents the glass pieces from sticking together and keeps the bead perforation from collapsing. In this way the sharp ends are softened, and according to the length of the cut segments and the heating temperature and time, cylindrical, ellipsoidal, oblate or disc-shaped glass beads may result. The larger beads were cut, often obliquely, from tubes with larger diameters. They are rarely finished in the same way as the smaller beads but were apparently rounded by placing the glass tubes on a plate made of metal or burnt clay, the plate being covered by a layer of most probably ash or fine sand to prevent fusion of the glass to the plate. The plate with the glass pieces was then placed in an oven or fireplace and the glass tubes were heated. It can often be seen that the beads are domed on what had been the upper side while the side in contact with the plate is flat and uneven from the release. In addition, the cut ends remain more distinct than those of the smaller drawn glass beads. To differentiate these beads from the small monochrome drawn glass beads we will refer to them as large monochrome drawn beads, with the understanding that in addition to, or, more likely because of their larger size, slightly different technological processes were used in their production.

There are large numbers of broken small monochrome drawn beads from Ribe, Hedeby and Birka, just as many of the beads have an irregular shape. In addition, there are many beads lacking a complete perforation, as well as examples of two or more beads fused together (**fig. 5i**, 4M75xD11495). Due to the large number of failed beads P. Steppuhn suggested that the beads might have been produced in Hedeby[16]. It might be more correct to advocate that the many finds of failed and broken beads must be due to the circumstance that the beads had been purchased »by the kilo« in the Near East, and then transported to Scandinavia in sacks or bags as loose beads that were sorted upon arrival at the marketplaces[17].

Cylindrical or facetted opaque green beads

Another specific type of glass bead, also from the late 8th and early 9th century, is a drawn glass tubular bead, often facetted with five or six sides (**fig. 4d**, ASR9x374 200061907). These beads are usually opaque green and are characterized by very high lead content. They have been found in quite large numbers at Haithabu[18], where they date to just around the year 800. These cylindrical or facetted opaque green beads most probably originate from the Near East, as described in earlier publications[19].

Opaque red and orange glass beads

Bead assemblages in southern Scandinavia from the 7th century are dominated by opaque, monochrome orange and red glass beads, most often with a diameter between 6 to 10 mm. Most are barrel-shaped, but they may also be oblate, cylindrical or conical, as well as facetted into cornerless cubes[20].

Opaque red and orange glass beads were used both in necklaces and as colourful elements in beaded breast ornaments, often arranged in four to five rows sometimes containing more than 100 beads kept in position with bead string spacers and terminal elements fastened to the woman's dress just below the shoulders. Such exclusive jewellery was most probably used by women from the social elite, and sometimes included gilt bronze fibulas and brooches, some inlaid with garnet. The red and orange opaque glass beads, often referred to as glass flus beads, are especially found in large numbers in the Mälaren region in Sweden, and on the Swedish island Gotland and the Danish island Bornholm in the Baltic Sea.
Even though the number of opaque red and orange glass beads from Ribe is relatively low, the structure and colour visually mirrored glass tesserae found at the marketplace. We included two orange and one red barrel-shaped beads as well as tesserae in the same colours in our analyses (**fig. 4e-h**, 5M74Dx5886, 5M74Dx6043).

CHANGES IN GLASS CHEMICAL COMPOSITION DURING THE SECOND HALF OF THE 1ST MILLENNIUM AD

In Western Europe, most glass objects that circulated during Late Antiquity and the Early Middle Ages, 4th -9th centuries, were made from soda-lime glass produced in Egypt or on the Syro-Palestinian coast. This glass was composed of calcareous sand with low alumina (Al_2O_3), typically between 2 and 3 wt % (weight percent) and rarely above 4 wt % [21], and natron, a relatively pure hydrated sodium carbonate [22]. The natron was probably collected in dry Egyptian lakes in the region of Wadi Natrum. Several centres for producing raw glass (primary workshops) that functioned during this period were located between Lebanon and Egypt [23]. In Western Europe, production centres for vessels and beads (secondary workshops) worked from blocks of raw glass from these primary workshops or from recycled glass (cullet, chunk or tesserae).
Archaeometric studies of Late Antique and Early Medieval glass objects have identified several compositional sub-groups probably related to the geographic origin of the primary workshops [24]. Two methods that may be used to identify the origin of the glass used to produce a particular object, although not necessarily the location of the secondary workshop where the object was made, are the comparison of the ratios of trace elements yttrium to zirconium (Y/Zr) and cerium to zirconium (Ce/Zr) to distinguish natron glass made in Egypt from that made in the Levant (as suggested by Gratuze), and the major and minor oxide ratios titania to alumina (TiO_2/Al_2O_3) and alumina to silica (Al_2O_3/SiO_2) to identify various types of colourless glass associated with different geographical and chronological sources [25]. However, there may still be considerable overlap between compositional types, much of this due to mixing of glasses from different sources in secondary workshops, and the overall picture is one of relative homogeneity in natron glass compositions.
Regarding Antiquity and the Early Middle Ages, a second type of soda-lime glass is found occasionally. It was fabricated using soda extracted from the ashes of halophytic plants such as Salicornia sp. or Salsola sp. This type of glass is distinguished from the preceding one by its higher content of potash (K_2O), magnesia (MgO) and phosphoric oxide (P_2O_5). Two families of plant ash soda glass have been identified. The first is characterized by similar quantities of magnesia and potash. It is frequently found among Egyptian red and green glasses of classical Antiquity [26], but was also used to make colourless blown vessels, with prominent finds in southern Egypt [27]. The second type of plant ash glass has higher magnesia content that exceeds that of potash. During Antiquity and the Early Middle Ages, this second type was produced at Sasanian and then Islamic centres in Mesopotamia, notably in Iraq [28].

If during the Early Middle Age the Roman production system is still in effect, an increase of soda glass recycling is observed from the 7th century [29]. This phenomenon stems directly from a progressive decline in the production of raw natron glass in the Levant and Egypt. Indeed, depending on the different regions, the production of natron glass and its importation in Europe seems to break off progressively from the end of the 8th century [30]. Over the course of the 9th and 10th centuries, in the eastern Mediterranean and Mesopotamia, soda-lime glass, produced from the ashes of halophytic plants, becomes the prevailing type of glass before characterizing the entire Mediterranean glass production by the end of the 12th century. In continental Western Europe, from the end of the 8th century raw glass imported from Egypt and the Levant is partly replaced by potash-lime glass made from forest plant ash (mainly potash and lime in variable proportions together with fairly high magnesia, phosphorus and manganese contents) [31]. Thus, in the Mediterranean and European worlds, radical changes are observed in glass production during the 9th century, resulting in the systematic use of fluxes obtained from plant ash instead of mineral deposits (natron). However, in Western Europe recycled natron glass seems to be used until the end of the 12th century for specific productions. These include cobalt-blue vessels decorated with white opaque glass, trails and spots, such as the Saint Savin bowl, and cobalt-blue stained-glass panels used in cathedral windows [32].

Two other main types of glass, where the calco-alkaline flux is partly or totally replaced by lead oxide (PbO) are also encountered from the end of the 8th century. The first, composed mainly of lead oxide, with PbO generally greater than 60 wt %, and silica. Alkaline elements are nearly absent in this lead glass *sensu stricto*. The second, composed of various proportions of lead oxide, silica, alumina, alkali oxides and lime, are the lead-alkali glasses, divided into lead-soda-lime glasses, lead-potash-lime glasses and the lead-soda-potash-lime glasses. In the 9th century, the first high-lead glasses seem to be used only for bead making and are mainly distributed in the Muslim world, Eastern Europe (Poland, Russia) and in the Caucasus region [33]. Around the late 10th and early 11th century, an emerald green glass made of more than 60 wt % lead oxide is commonly used for vessel production in the Muslim world [34].

GOALS OF THE STUDY

With this study, we hoped to answer the following questions:

- What glass chemical types are found at Ribe?
- What insight do the chemical composition results give into bead making processes?
- What was the glass raw material and where was it coming from, along which trade networks?
- Also, how well do the chemical types of the beads and bead making debris reflect the identified raw material?
- How does the Ribe data help us understand the changing patterns of trade in the 8th-9th century?

MATERIALS AND METHODS

In connection with our studies on the glass bead making technology in Ribe and the investigations on the raw glass used in the local glass bead production, we analysed 161 samples of glass beads (101), raw glass (10), mosaic tesserae (29) and waste from glass bead making (18), including fragments from 3 glass smoothers found at the site (see **tab. 1** for the main typological groups). As many of the beads and some of the glass waste were polychrome, we performed a total of 272 analyses (see **tab. 2** for the distribution of these groups by colour).

Main glass types	Number of objects	Total Beads	Segmented Beads	Monochrome Beads	Mosaic cane & Polychrome wound Beads	Tesserae	Waste	Raw glass	Smoother
Antique and Late Antique natron and soda plant ash glasses	104	47		13	34	29	18	10	
High-magnesia soda plant ash glasses (Islamic-mesopotamian)	45	45	19	17	9				
High-lead glasses	4	4		4					
High-alumina mixed-alkali red and orange glass	3	3		3					
Potash and lead-aluminous-lime glass beads and smoothers	5	2		1	1				3

Tab. 1 Distribution of the analysed objects according typologies and glass groups. – (Table CNRS/IRAMAT-CEB).

The analyses of the glass beads and objects were conducted at the Centre Ernest-Babelon of the IRAMAT (CNRS/Université d'Orléans, France), using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). The instrumentation consisted of a VG UV laser probe working at 266 nm (NdYAG laser with quadrupled frequency, operating at 3-4 mJ power and 7 Hz) coupled with a Thermo Fisher Scientific ELEMENT XR mass spectrometer. LA-ICP-MS allows a nearly non-destructive analysis, invisible to the naked eye, of the glass objects[35]. Analytical parameters were as follows: ablation time was set to 70 seconds: 20 seconds pre-ablation, so that contamination could be removed, and 50 seconds collection time. Fresh fractures were analysed where possible to reduce potential contamination. Blanks were run between each sample. Spot sizes were set to 100 µm (although reduced to 70 µm when saturation occurred). Two areas were analysed per sample; heterogeneity and agreement between runs was consistently good. During analysis live counts were continuously observed: when element spikes signifying the presence of inclusions were observed, results were discarded and a new site selected.
Calibration was performed using five reference standards: NIST610, Corning B, C and D, and APL1 (an in-house reference glass used for chlorine determination) were run periodically (every 15 to 20 samples) to correct for eventual drifts. The standards are used to calculate the response coefficient (k) of each element[36]. The measured values were normalised against ^{29}Si, the internal standard. Concentrations are calculated assuming that the sum of the concentrations of the measured elements is equal to 100 wt %. In total, 52 elements were recorded. For the major and minor elements accuracy and precision were within 5 % relative and within 10 % for most trace elements.

RESULTS AND DISCUSSION

According to the principal constituents brought by the silica source (SiO_2, Al_2O_3 and CaO) and the fluxes (Na_2O, MgO, K_2O, P_2O_5, PbO and also CaO), the results obtained enable the classification of the 272 analysed glasses into five main compositional groups which can be subdivided into eight subgroups (see **tab. 3** for the average compositions of the main identified groups, and **fig. 6** for distribution by MgO and K_2O content). The first group consists of 141 glasses made with natron and is subdivided into two subgroups, one with 138 glasses and the other with only three glasses. The second group is made of 117 glasses made

	Total number of analysed glass	Black (Fe)	Black (Fe, Pb)	Blue (Co)	Blue (Cu)	Colourless or natural tint (light blue, green amber, Fe)	Green (Cu)	Orange (Cu_2O)	Purple (Mn)	Red (Cu)	White (Sb or Sn)	Yellow (Sb or Sn)
Beads, waste and tesserae, Antique and Late Antique natron glass	138	6	1	47 (13 chunks or tesserae)	2	8	9		2	17 (4 tesserae)	25 (4 tesserae; 10/25 with high Mg)	21 (5 tesserae)
Beads, waste and tesserae, Antique and Late Antique soda plant ash glass	27						1	4 (4 tesserae)		21 (4 tesserae)		1 (perhaps pollution from surrounding glasses)
Beads, Egypt 2 Islamic natron glass	3									3		
Beads, Mesopotamian Islamic soda plant ash glass	90			17		32	8			7	8	18
Beads, high-lead glass (Islamic)	4						4					
Beads, red and orange, high-alumina mixed soda-potash glass (South-Asian?)	3							2		1		
Beads, potash glass	4				1	2				1		
Smoother, potash glass	1	1										
Smoothers, lead glass made from Melle slag	2	2										

Tab. 2 Distribution of the different coloured glasses among compositional glass groups identified in Ribe. – (Table CNRS/IRAMAT-CEB).

Oxide	Beads, waste and tesserae, Antique and late Antique natron glass (138)		Beads, waste and tesserae, Antique and Late Antique soda plant ash glass (27)		Beads, Egypt 2 natron glass (3)		Beads, Mesopotamian Islamic soda plant ash glass (90)		Beads, high-lead (4)		Beads, red and orange, high-alumina mixed soda-potash glass (3)		Beads, potash glass (4)		Smoother, potash glass (1)	Smoothers, lead glass made from Melle slag (2)	
	av.	std.	av.	std.	av.	std.	av.	std.	av.	std.	av.	std.	av.	std.		av.	std.
Na_2O	14.7	2.4	12.5	2.5	12.8	0.5	13.4	1.5	0.052	0.016	5.02	0.81	1.77	0.74	0.91	1.07	0.30
MgO	0.70	0.35	2.03	0.66	1.08	0.10	4.23	0.54	0.080	0.034	0.47	0.17	4.88	0.54	4.22	1.62	0.04
Al_2O_3	2.33	0.28	2.48	0.45	2.72	0.14	1.82	0.34	0.19	0.05	10.7	1.1	2.78	0.20	1.81	7.49	1.86
SiO_2	64.9	7.5	57.6	5.9	67.5	1.9	64.3	4.6	25.6	1.0	61.8	4.8	58.8	3.0	51.8	46.6	5.1
P_2O_5	0.17	0.22	0.81	0.33	0.29	0.04	0.27	0.20	0.027	0.016	0.16	0.09	2.44	0.27	5.88	1.72	0.11
Cl	0.93	0.22	0.84	0.14	0.68	0.10	0.68	0.12	0.16	0.02	0.40	0.13	0.44	0.15	0.44	0.15	0.002
K_2O	0.54	0.17	1.58	0.65	1.09	0.10	2.79	0.44	0.038	0.008	3.95	0.45	11.8	0.5	15.2	3.52	0.68
CaO	6.53	0.93	8.07	1.25	9.23	0.31	6.44	0.92	0.42	0.16	3.11	1.18	13.3	1.3	17.9	13.3	0.6
TiO_2	0.12	0.04	0.19	0.05	0.23	0.03	0.12	0.02	0.0089	0.0034	0.12	0.02	0.27	0.01	0.11	0.20	0.02
MnO	0.48	0.32	0.50	0.31	0.35	0.11	0.57	0.37	0.0024	0.0009	0.065	0.029	0.76	0.09	0.77	0.23	0.001
Fe_2O_3	1.39	1.67	1.94	0.60	1.35	0.24	0.93	0.53	0.13	0.04	1.85	0.41	1.44	0.43	0.57	2.92	0.14
CuO	0.56	1.30	2.66	2.39	1.38	0.54	0.43	0.85	0.38	0.09	10.9	7.8	0.51	0.63	0.012	0.028	0.004
SnO_2	0.57	1.22	0.41	0.27	0.15	0.06	1.12	2.58	0.0076	0.0026	1.07	0.60	0.029	0.028	0.0023	0.0053	0.003
Sb_2O_3	1.47	1.97	0.39	0.34	0.051	0.043	0.0028	0.0048	0.21	0.09	0.015	0.009	0.019	0.020	0.0000	0.42	0.05
PbO	4.36	9.37	7.62	6.08	0.68	0.53	2.42	4.98	72.5	1.0	0.073	0.101	0.20	0.29	0.0014	19.6	6.5
CoO	0.021	0.028	0.0056	0.0048	0.0033	0.0019	0.031	0.066	0.0002	0.0000	0.0008	0.0005	0.0013	0.0004	0.0003	0.0010	0.00002
ZnO	0.056	0.16	0.13	0.20	0.19	0.09	0.096	0.189	0.015	0.008	0.075	0.066	0.21	0.22	0.038	0.11	0.05
B_2O_3	0.049	0.010	0.053	0.011	0.032	0.004	0.034	0.004	0.0019	0.0004	0.022	0.002	0.055	0.004	0.055	0.031	0.003
SrO	0.049	0.007	0.070	0.012	0.035	0.009	0.056	0.008	0.0040	0.0028	0.0078	0.0027	0.044	0.004	0.081	0.071	0.021
Rb_2O	0.0011	0.0003	0.0010	0.0004	0.0020	0.0002	0.0015	0.0006	0.0001	0.0000	0.028	0.003	0.023	0.001	0.019	0.013	0.003
ZrO_2	0.0089	0.0028	0.010	0.003	0.021	0.003	0.016	0.004	0.0003	0.0001	0.036	0.013	0.024	0.004	0.014	0.016	0.0004
BaO	0.027	0.009	0.027	0.006	0.082	0.050	0.017	0.005	0.012	0.010	0.014	0.007	0.17	0.02	0.19	0.85	0.62
UO_2	0.0001	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0008	0.0002	0.0001	0.0000	0.0001	0.0007	0.0001

Tab. 3 Average compositions in weight % of oxides of the main groups of glass identified among Ribe's glass objects (beads, waste, tesserae, smoothers) analysed. – (Table CNRS/IRAMAT-CEB).

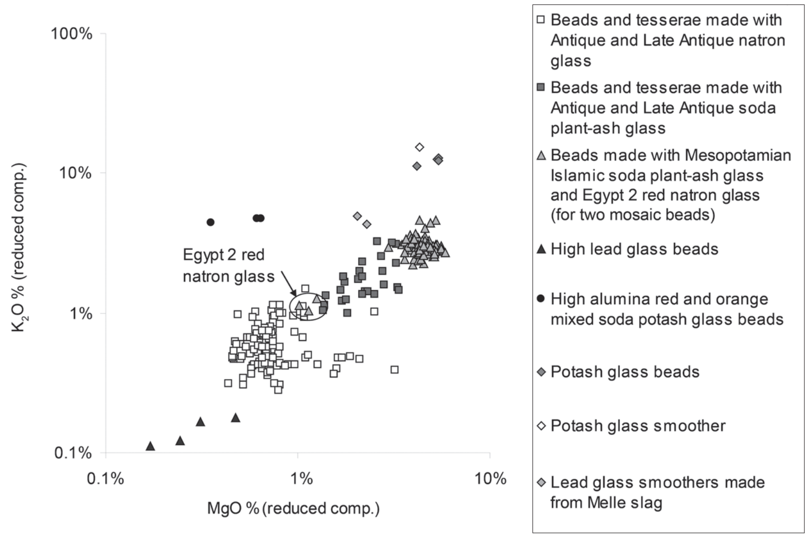


Fig. 6 Distribution of the different glass groups identified in Ribe according to their MgO and K_2O contents. Natron glasses (empty squares) are characterized by low content of potash and magnesia. Two groups of plant ash glass characterized by different level of magnesia and potash are identified. The first group (grey squares) correspond to recycle Antique and late Antique red and green glasses (Nenna and Gratuze 2009) while the second group (grey triangles) correspond to Mesopotamian Islamic plant ash glass. Note the presence of some high-magnesia natron glass (mainly white, Nenna and Gratuze 2009) and the presence of three natron Egypt 2 Islamic glass (Gratuze/Pactat/Schibille 2018). – (Diagram CNRS/IRAMAT-CEB).

from soda plant ashes and is also subdivided into two subgroups which include respectively 27 and 90 glasses. The first subgroup is characterized by similar amounts of magnesia and potash while the second subgroup has higher magnesia contents.

The 14 remaining glasses form the three last groups. Three of these glasses were made with a high-alumina sand (Al_2O_3 > 9 wt %) fused with mixed soda-potash fluxing agent with similar contents of soda and potash ranging from 3 to 6 wt %. Five others are potash-lime glasses made with forest plant ashes. The six last glasses are lead glasses, four of these are high-lead glasses with PbO between 71 and 74 wt % and SiO_2 between 24 and 27 wt %, and the other two are characterized by the presence of high levels of lime, lead oxide, alumina and potash.

Antique and Late Antique natron and soda plant ash glasses

Our analyses of the glass remains found in Ribe show that they mainly consist of original or recycled, Antique and Late Antique, natron soda-lime glass (141/272). Of these glasses 138 originate from the 8^{th} century layers of the market place and can be associated with local glassworking. To this large group of natron glasses we can add 27 plant ash soda glasses with similar levels of magnesia and potash that were recovered in the same contexts and usually associated with natron glass in the same objects. Three natron glasses come from a later context and were associated in objects with the second subgroup of soda plant ash glasses; they will be discussed with that group.

While most glass colours are represented in the natron group (7 black, 47 dark and 2 greenish blue, 8 natural tint, whether colourless, amber-brown, pale green or pale blue, 9 green, 17 red, 2 purple, 25 white and 21 opaque yellow), with the exception of 1 yellow glass inserted in green glass in a mosaic glass bead, 26 of the above plant ash glasses are either red (21), orange (4, all tesserae) or green (1). For the one yellow glass with a plant ash composition, we cannot exclude that the magnesia and potash detected in the yellow glass are due to a contamination from the green glass. In this large group of 165 glasses we find all the tesserae and the glass wastes and chunks of our corpus.

In terms of colourants, the seven black glasses were coloured with iron oxide from 3.3 to 8.5 wt %; one of them is characterized by high lead content of 30 wt % PbO and very high iron 14.5 wt % Fe_2O_3, a

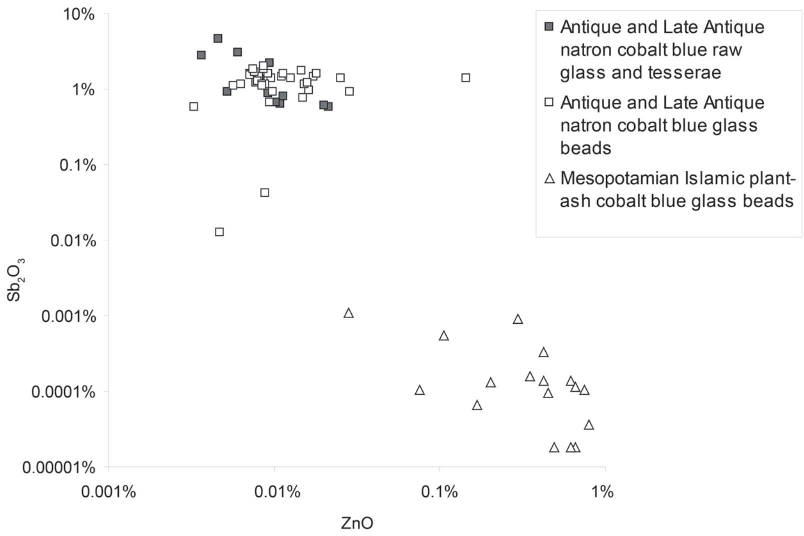


Fig. 7 Concentrations of ZnO vs Sb_2O_3 for the different cobalt-blue glasses analysed from Ribe. The natron Antique and late Antique glasses are clearly distinguished from the Islamic soda plant ash glasses by their higher antimony contents. – (Diagram CNRS/IRAMAT-CEB).

composition which is occasionally found in Merovingian contexts[37]. The 47 dark blue glasses, coloured with cobalt, are divided into 4 tesserae, 9 production wastes or chunks, and 34 beads or parts of beads. The compositions of the latter, similar to those of the tesserae, illustrate well the recycling of glass tesserae for bead making. As shown in **figure 7**, all the cobalt-blue glasses are characterized by high antimony contents, with beads, waste and tesserae showing similar levels. Moreover, in a recent study on Late Antique and Early Mediaeval cobalt-blue glasses we show that three main cobalt groups can be identified[38]. Two of these groups are characterized by low zinc contents and either high or low ratios of cobalt versus nickel oxides; this CoO/NiO ratio is typically greater than 24 before the end of the 4th century and less than 6 after the end of the 4th century. Those cobalt-blue glasses with intermediate ratios probably result from the mixing of these two groups. The three types of natron cobalt-blue glasses from Ribe exhibit similar distributions of cobalt to nickel oxides ratios: from 4.9 to 26.2 for the beads, from 6.5 to 22.8 for the waste and from 11.5 to 24.4 for the tesserae. While a few samples had either very high or very low ratios, indicating production either before or after the end of the 4th century, most of the cobalt-blue glasses, with intermediate ratios, illustrate the recycling of Antique and Late Antique glass for both mosaic tessera production and glass bead making.

The red and orange natron and soda plant ash glasses were coloured with copper in its metallic form for the red glass and in the cuprite form (CuO crystals) for the orange glass. The wide range of compositions illustrates the different recipes used to produce these colours and the diversity of the raw material. The red glasses are divided into 17 natron glasses and 21 soda plant ash glasses while the 4 orange glasses contain only soda plant ash glass. For the red glass, among the oxides which present the widest range of concentration we find those of iron, Fe_2O_3 from 0.9 to 4.4 wt %; copper, CuO from 0.6 to 13.6 wt %; zinc, ZnO from 0.1 to 1.1 wt %; tin, SnO_2 from 0.03 to 1.6 wt %; antimony, Sb_2O_3 from 0.002 to 1.1 wt %; and lead, PbO from 0.02 to 17.3 wt %. These wide ranges illustrate both the diversity of recipes and of raw material used as colouring agents, including pure copper, brass and bronze. The four orange tesserae show less variability in composition. In the same way, if the 2 blue and the 9 green glasses coloured with copper exhibit less variability than the red glass, the observed range of compositions shows both the presence of yellow opacifier (lead antimonate and/or stannate) in the green glass and the variability of material used as colouring agents (various copper alloys).

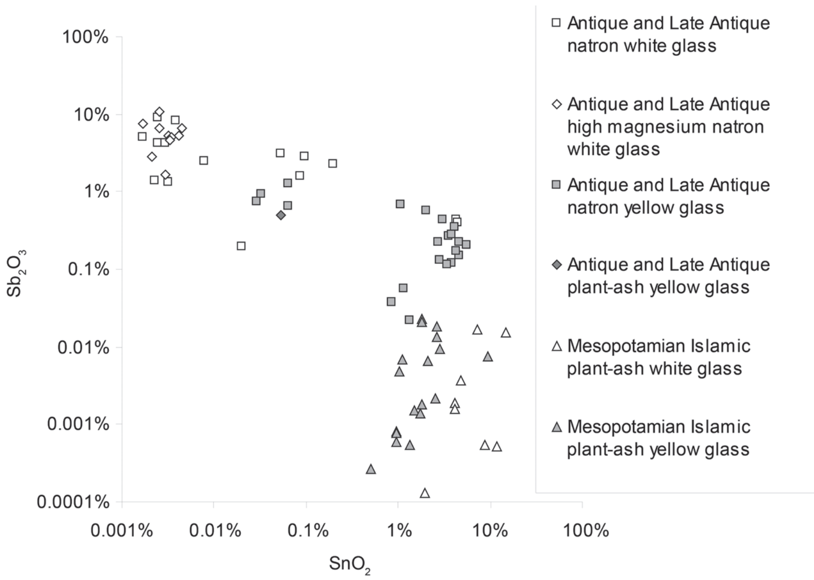


Fig. 8 Concentrations of SnO_2 vs Sb_2O_3 for the different white and yellow glasses analysed from Ribe. The natron Antique and late Antique glasses are clearly distinguished from the Islamic soda plant ash glasses by their opacifiers. While antimony and tin are both used either alone or mixed in natron Antique and late Antique glasses, only tin is used in Islamic soda plant ash glasses. – (Diagram CNRS/IRAMAT-CEB)

The 2 purple natron glasses were coloured with manganese oxides, with MnO between 1.8 and 2.1 wt %.
We analysed 25 opaque white glasses: 20 elements of glass beads, 4 tesserae and 1 glass rod. These form two main groups of natron glasses, one, 15 glasses, with magnesium oxide contents lower than 1 wt %, and the other, 10 glasses, with higher MgO contents between 1.1 and 3.4 wt %. These two groups are similar to those identified in Antique mosaic glass[39]. The opacifiers are antimony, probably in the form of calcium antimonate, for 23 glasses and tin oxide for the 2 others (**fig. 8**). The presence of tin oxide, either as the main opacifier or at concentrations ranging from 0.08 to 0.2 wt % was only observed in the low magnesium glasses.
Tin, probably in the form of lead stannate, is the main colouring and opacifying agent identified in the yellow opaque glasses (17/22). In contrast, lead antimonate is the principal colouring and opacifying agent in three beads and two tesserae but is always associated with some amount of lead stannate (**fig. 8**). Starting in the 4th and 5th centuries and spreading from the East towards the western Mediterranean, tin became increasingly important as the principal colouring and opacifying agent for yellow glass (lead stannate replaced lead antimonate) and white glass (tin oxide replaced calcium antimonate)[40]. The presence, in the analysed beads of both tin and antimony as opacifiers, along with the high-magnesia natron white glasses, shows that both Antique and Late Antique glasses have been recycled in the Ribe glass bead workshop.
As mentioned above, comparison of the trace element ratios Y/Zr and Ce/Zr may indicate the Levantine or Egyptian origin of the natron glasses, with glass produced in the Levant having consistently higher ratios than glass produced in Egypt. For our 168 Ribe natron and natron-associated plant ash glasses, only 15 % had a definite Levantine origin while 59 % were Egyptian, with the remaining 26 % probably mixtures of Levantine and Egyptian primary glass. While the samples identified as fragments of fresh, raw glass were exclusively Egyptian, all of the other categories, including mosaic tesserae, were included in the Levantine, Egyptian and mixed groups. Because most of our samples were heavily coloured, it is difficult to use the ratios TiO_2/Al_2O_3 and Al_2O_3/SiO_2 to identify early and late compositional types. However, based on cobalt to nickel ratios for the cobalt-blue samples, roughly 20 % of these glasses were probably 4th century or earlier, 20 % probably produced from the 5th to 8th century, and the remainder heavily mixed. Referring again to the 9 cobalt-blue »raw« glass samples, only 1 was pre-5th century, 5 were 5th century or later, and 4 were mixed early and late. While some of these samples may represent fresh supplies of unworked glass coming

to Ribe, the compositional evidence is not strong, and it is possible that many of our raw glass samples were simply fragments chipped from mosaic tesserae.

High-magnesia soda plant ash glasses and related natron and high-lead glasses

The soda plant ash glasses discussed here belong to the second type of soda-lime plant ash glass, characterized by magnesia levels exceeding those of potash. These glasses are similar to those originating from Veh Ardasir, Iraq [41], and have therefore probably been produced in the old Mesopotamian areas. We'll also discuss here 3 natron glasses associated with this type of plant ash glass in 2 of the studied beads, as well as 4 high-lead glass beads. All these glasses originate from late 8th and early 9th centuries contexts.
Starting in the end of the 8th century, halophytic plant ash soda-lime glasses progressively replaced natron glass in the Mediterranean zone [42]. This change doesn't seem to have occurred at the same time in the Levant and in Egypt. If plant ash glass started to replace natron glass as soon as the end of the 8th century in the Levant, the production of natron glass continued in Egypt during a long part of the 9th century with evidence for different types of natron glass produced in Egypt during the 8th and 9th centuries. Among these, a compositional group named Egypt 2, whose production began during the last quarter of the 8th century in Egypt [43], was identified in two of the beads recovered at Ribe. In these polychrome beads, the red/blackish glass has an Egypt 2 natron glass composition, while the white and yellow glasses have a plant ash Mesopotamian composition (**fig. 4i**, ASR9x165). According to their particular typology, wound beads decorated with slices of mosaic cane, these two beads may have been made in Viking workshops by recycling Egyptian Islamic-period natron glass and Mesopotamian soda plant ash glass.
Compared to the preceding plant ash glass group, this large group (90 glasses) appears more homogeneous in composition while presenting a larger diversity in colour: 17 dark blue, 32 natural tint, whether amber-brown, pale green or bluish, 8 green, 7 red, 8 white and 18 yellow. We also notice a complete change for most of the colouring agents used for this glass compared to those used to colour Antique and Late Antique natron glasses.
For example, the later soda plant ash cobalt-blue glasses (17 analyses) exhibit several differences from the natron cobalt-blue samples: antimony contents are all below 0.001 wt % while they are all above 0.012 wt % for natron blue glasses (**fig. 7**); zinc contents are higher (**fig. 7**) and nickel content lower, with an average cobalt to nickel ratio of 43 compared to 14 for the natron glasses as a group. In a recent paper it was shown that these features are typical of a new cobalt ore exploited in the Islamic world from the 9th century onward [44].
Likewise, the opacifiers used for white (8) and yellow (18) glasses are only based on tin compounds, tin oxide for white opaque glasses and lead stannate for the yellow opaque glasses, with very low antimony contents below 0.023 wt %.
For red and green Mesopotamian plant ash glasses, although the colourants are similar to those of earlier samples, we observe an important variability of composition reflecting both different recipes and the large panel of raw materials used as colouring agents.
A large part of the beads discussed here are segmented metal foiled glass beads (19/45). For most of these the outer glass layer has an amber-brown tint (9), or is colourless (5), but it can also have a blue (4) or a greenish tint (1). When possible, the metal foil has been analysed and in every case the presence of large amounts of silver has been observed. When the outer layer has an amber-brown hue it gives the bead a golden appearance. The separate analysis of the outer brown glass layer and of the inner colourless layer does not show any compositional difference between the two glasses. Their manganese and iron oxide

contents are similar, and as it was not possible to analyse sulphur, we can only hypothesise that theses colours were obtained by controlling the oxidation-reduction conditions of the glass firing atmosphere to encourage the creation of an iron-sulphide chromophore.
We'll mention here four of the high-lead glass beads that also probably originate from the east (**fig. 4d**, ASR9x374 200061907). The main particularity of this type of glass is to contain essentially lead oxide and silica. These two compounds make up from 97.5 % to 98.5 % of the total composition of the glass. The main remaining oxides are those of calcium, 0.3 to 0.7 wt %, copper, 0.3 to 0.5 wt %, alumina, 0.1 to 0.3 wt %, arsenic, 0.1 to 0.3 wt %, antimony, 0.1 to 0.3 wt % and iron, 0.1 to 0.2 wt %, that altogether sum between 1.3 and 2.1 wt %. As mentioned above, in the early 9th century, it seems that only glass beads are reported with this particular composition, while in the 10th and 11th centuries the same glass was also used to produce vessels[45].

High-alumina mixed-alkali red and orange glass

Three opaque red (one) or orange (two) barrel-shaped beads show a composition which differs from all known Mediterranean or European glasses in both main chemical components and colouring recipes (**fig. 4**, M74Dx5886, 5M74DxD6043). These three beads were made from a mixed soda-potash glass characterised by high concentrations of alumina, greater than 8 wt %, and trace elements including cerium, thorium, uranium and zirconium. The red colour is from metallic copper, CuO 2.6 wt %, and the orange from a mixture of small and large cuprite crystals with CuO from 12 to 18 wt %. The origin of this particular group of glasses, mainly found during the 7th and 8th centuries in Sweden, Denmark and northern Germany, is still not completely solved. However, their high alumina and trace elements contents together with the use of mixed soda-potash fluxes and different colouring recipes point to a possible South Asian origin[46].

Potash and lead-aluminous-lime glass beads and smoothers

The five last studied objects (two glass beads and three fragments of glass smoothers making up eight analyses) show a completely different composition (**fig. 4c**, ASR9x21 A11). They are made with potash-lime glass (the two glass beads and one of the smoothers) or recycled lead slag from the Carolingian lead mine at Melle in France (the two other smoothers), and illustrate the first Europeans glasses made from the end of the 8th century onwards[47].

CONCLUSION

The compositional data, in the context of previous archaeological and morphological study, goes a long way toward answering the archaeological questions posed above. For the first question, what varieties of glass were found at Ribe, we found at least eight different compositional types, ranging from Roman and Late Antique natron glass, as well as its higher magnesia and potash variants, all produced in Egypt or on the Levantine coast, to a more uniform high-magnesia plant ash glass from production sites in Mesopotamia. Several less common types include red and orange high-alumina mixed-alkali glass with an unknown, although possibly South Asian origin, high-lead glass probably also from Mesopotamia, and potash-lime glass

produced in Europe. In many cases, glass types were mixed, indicating extensive re-use and recycling in the post-Roman period, where glasses produced even hundreds of years apart might be re-melted together to make new objects.
Our second question was what insights the chemical composition results give into bead making processes at Ribe. We studied two types of possible raw materials: mosaic tesserae and glass fragments of various sizes (largest 2 cm diameter) that were not clearly from a broken bead or vessel. All tesserae were natron or natron-related plant ash glass, and either Egyptian, Levantine, or a mixture of the two. These mixtures suggest that mosaic tesserae production in secondary workshops persisted at least into the 6th century. The raw-glass chunks were all cobalt-blue and contained significant amounts of antimony. As discussed above, it is not entirely clear whether this »raw glass« represents a supply of fresh, sometimes recycled, glass coming to Ribe, or the fragments we studied were simply broken from mosaic tesserae. In any case, the close compositional agreement between raw materials and bead making debris or finished beads strongly supports the model of secondary production using imported raw materials, and that all technological steps, including manufacture of ribbon and mosaic canes, were performed by the bead makers working at Ribe. However, we must note that the 26 mosaic tesserae and 9 raw glass fragments that we studied were a very small sample of the thousands found at the site, and a full interpretation may have to await further study of possible raw materials at Ribe. In terms of trade networks, the mosaic tesserae and possible raw glass fragments all have Egyptian or Levantine origins, and represent the continuation of long-standing trade networks linking Scandinavia with territory to the south. The close study of mosaic tesserae from well documented production or use sites may help to add additional geographic details to these trade networks.
One other potential source of glass for bead making would be recycling of some of the many broken vessels found at the Ribe marketplace. Most of these vessels would have been colourless, and because there is very little colourless glass in the Ribe beads, the vessel glass could have been combined with strongly coloured glass from mosaic tesserae, resulting in a coloured glass variably diluted in colouring elements such as cobalt, copper or antimony. However, there is little physical evidence for such re-melting at the site, and compositional evidence would require a much greater sample size for both tesserae and raw glass fragments, since there is already great individual variability from one sample to another. In any case, further study of the glass vessel fragments, as well as a more intensive sampling of tesserae and what appear to be raw glass fragments, could be a useful approach for a more complete understanding of the full range of technological approaches and choices made by the Ribe bead makers.
Our third archaeological question was to consider how the Ribe glass results help us to understand the changing patterns of trade in the 8th-9th century. Here, the Ribe results provide a fine-tuned chronology for the change in the importance of locally or regionally produced beads to wholesale import from the Islamic world. These imports begin shortly after the Abbasid caliphate, with its capital in Baghdad, was established in AD 750. The close timing reflects a rapid ramp-up in glass bead production, possibly in some of the same areas in Iraq that were already important for glass production in the Sasanian Empire. In addition, the many types of mosaic canes used to make both beads and wall tiles, as at Samarra [48], provide evidence for new glass technologies, some most likely brought from Egypt and the Levant, that were not present in Sasanian glass. The chemical compositions of the new types of late 8th century beads at Ribe, in the absence of evidence for raw glass or bead making debitage that might suggest local production, provides strong confirmation for the import of these finished beads from Mesopotamian centres. This change required a major shift in trade focus from the south to the east, with increasing importance of the Russian river systems in trade with Scandinavia. Similar changes in southern Europe, with evidence from 9th century Albania [49], and Southeast Asia, where identical Abbasid glass beads have been found at many sites in Thailand, including Thung Tuk on the west coast of the Thai/Malay Peninsula, and Chaiya on the east coast [50], would have

required a major realignment in far-reaching trading systems. In addition, it is likely that the increased scale of raw glass and finished bead production will have had significant economic, technological, social and political effects within the Caliphate.

Notes

1) Feveile 2006.
2) Bencard 1973; 1979. – Näsman 1979. – Bencard/Jørgensen/Madsen 1990. – Jensen 1991. – Feveile/Jensen 2000. – Sode 2004. – Feveile 2006; 2013.
3) Feveile/Jensen 2000. – Feveile 2013.
4) Thanks to M. Søvsø, Sydvestjyske Museer, Ribe, for given the information on the number of excavated glass which cover the excavations up to 2016.
5) Sode/Gratuze/Lankton 2017.
6) Callmer 2018.
7) Callmer 1995.
8) Andrae 1975.
9) Callmer 1977.
10) Spaer 2001. – Sode 2004. – Sode/Feveile 2002. – Sode/Feveile/Schnell 2010. – Delvaux 2017. – Callmer 2018.
11) Callmer 2018, 31.
12) Lundström 1981.
13) Rodziewicz 1984.
14) Danielsson 1973. – Callmer 2018.
15) Steppuhn 1998.
16) Steppuhn 1998.
17) Francis 2002. – Sode 2004. – Callmer 2018.
18) Steppuhn 1997.
19) Callmer 1977; 2018. – Steppuhn 1997; 1998.
20) Sode/Gratuze/Lankton 2017.
21) Brill 1999. – Schibille 2011. – Rehren et al. 2015.
22) Shortland et al. 2006.
23) Freestone/Gorin-Rosen/Hughes 2000. – Freestone/Hughes/Stapleton 2008. – Rehren et al. 2010.
24) Freestone/Gorin-Rosen/Hughes 2000. – Foy et al. 2003. – Rehren/Freestone 2015. – Velde 2013. – Velde/Motteau 2013. – Freestone et al. 2018. – Phelps et al. 2016. – Pion/Gratuze 2016. – Schibille et al. 2019.
25) Freestone et al. 2018.
26) Nenna/Gratuze 2009. – Jackson/Cottam 2015. – Jackson/Cottam/Lazar 2015.
27) Rosenow/Rehren 2018.
28) Mirti et al. 2009. – Ganio et al. 2013. – Pion/Gratuze 2016.
29) Freestone 2015. – Mirti et al. 2001.
30) Whitehouse 2002. – Phelps et al. 2016. – Schibille et al. 2019.
31) Van Wersch et al. 2016. – Velde 2009. – Wedepohl/Winkelmann/Hartmann 1997. – Wedepohl/Simon 2010.
32) Brill 1999. – Foy 2001. – Simon-Hiernard/Gratuze 2011. – Sterpenich/Libourel 1997.
33) Bezborodov 1975.
34) Krueger 2014.
35) Gratuze 2016.
36) Gratuze 2016.
37) Pion/Gratuze 2016.
38) Gratuze/Pactat/Schibille 2018.
39) Nenna/Gratuze 2009.
40) Tite/Pradell/Shortland 2008.
41) Mirti et al. 2009. – Ganio et al. 2013.
42) Shortland et al. 2006. – Whitehouse 2002. – Phelps 2018. – Schibille et al. 2019.
43) Schibille et al. 2019.
44) Gratuze/Pactat/Schibille 2018.
45) Krueger 2014.
46) Sode/Gratuze/Lankton 2017.
47) Velde 2013. – Velde/Motteau 2013. – Wedepohl/Simon 2010. – Sode/Gratuze 2015. – Pactat et al. 2017. – Gratuze et al. 2017.
48) Schibille et al. 2018.
49) Neri/Gratuze/Schibille 2019.
50) Chaisuwan/Naiyawat 2009.

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Zusammenfassung

Die reichhaltigen Überreste von Glasperlen und der Perlenherstellung aus Ribe, die in das 8. und die erste Hälfte des 9. Jahrhunderts datiert werden können, sind die am besten erhaltenen Belege für die frühmittelalterliche Produktion und den Handel mit Glasperlen in Nordeuropa. Unsere Studie, die sich auf die Morphologie der Perlen, die Herstellungstechnologie und die chemische Zusammensetzung stützt, zeigt, dass die Perlenproduktion vor Ort, vor allem im frühen und mittleren 8. Jahrhundert, aber auch im 9. Jahrhundert, gut belegt ist. Die verwendeten Rohstoffe stammen hauptsächlich aus dem römischen und spätantiken Ägypten, aber auch aus der Levante. Im letzten Drittel des 8. Jahrhunderts verschiebt sich dieses Bild hin zu einem Großimport fertiger Perlen aus den abbasidischen Zentren im Irak, wenngleich ein geringerer Anteil weiterhin in lokaler Produktion gefertigt wurde. Die Belege aus Ribe liefern eine genaue Chronologie für diesen Wandel sowie einen detaillierten Überblick über die neuen Produkte aus der islamischen Welt. Diese bedeutende Neuausrichtung des Handels von Süden nach Osten hatte erhebliche Auswirkungen nicht nur für die Gesellschaften in Nordeuropa, sondern auch für das Kalifat, wo der stark gestiegene Umfang der Produktion und des Handels mit Glas und anderen Materialien wahrscheinlich signifikante wirtschaftliche, technologische, soziale und politische Folgen hatte.

Summary

The abundant glass bead and beadmaking remains from Ribe, closely dated to periods throughout the 8th and first half of the 9th century, provide the best-preserved evidence for early medieval glass bead production and exchange in Northern Europe. Our study based on bead morphology, manufacturing technology and chemical composition shows strong support for on-site bead production, most importantly in the early and mid-8th century but also into the 9th century, using raw materials mainly from Roman and Late Antique Egypt but also the Levant. By the last third of the 8th century this picture changes to wholesale import of finished beads from Abbasid centres in Iraq, albeit with a reduced level of continued local production. The Ribe evidence provides a fine-grained chronology for this change as well as a detailed look at new products coming from the Islamic world. This major shift in trade focus from south to east would have important implications not only for societies in Northern Europe, but also in the Caliphate, where the greatly increased scale of production and trade of glass and other materials likely had significant economic, technological, social and political effects.