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## Viking Age Windows

*A reassessment of windowpane fragments based on chemical analysis (LA-ICP-MS) and their find contexts*

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### ABSTRACT

In the last 25 years a conspicuous amount of plane glass – windowpane fragments – has surfaced on archaeological sites from the Viking Age. These finds have not received scholarly attention as they are not recognised as a genuine prehistoric (*i.e.* pre-1050 Scandinavia) occurrence. This paper aims to investigate a select group of archaeological localities that all have a significant amount of glass objects and fragments, and which also serve as mainstays for continental influences, commercial trade, as well as ritual activities. It offers the study of the chemical composition of these windowpane fragments, their distribution, provenience, and discusses their potential use as windows in Viking Age Scandinavia. Based on the chemical composition of the analysed plane glass (via LA-ICP-MS) the paper argues, firstly, that the glass most likely should be dated to the 9<sup>th</sup> to 11<sup>th</sup> centuries; secondly, that there are two possible import paths of raw material with one recognized at the early emporia based on east Mediterranean types of glass, and another with a continental type of glass found at the aristocratic sites. Finally, the paper proposes that the windowpanes very likely could have been used in contemporary glassed windows placed in wooden buildings at these sites.

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## The context of window glass in Scandinavia

Glass from windowpanes have not been regarded as genuine prehistoric objects (*i.e.* pre-1050 in Scandinavia), and have for that reason avoided the eye of the Viking Age researcher. Accordingly, the present paper aims to investigate a select group of archaeological localities that all have a significant amount of glass objects and fragments of plane glass, that is, windowpanes.

The sites of the present study (Haithabu, Germany; Birka and Uppåkra, Sweden; Sorte Muld, Tissø, and Strøby Toftegård, Denmark) all have a significant biographical 'depth' where the use-phase of the sites span several centuries, in some cases perhaps even a millennium (Figure 1). The sites at Tissø, Strøby Toftegård, Sorte Muld, and Uppåkra are all characterized by a significant number of high-status objects found in the central areas

that are also dominated by monumental architecture (Adamsen et al. 2008; Beck 2017; Harrison 2022; Jørgensen 2002, 2005, 2009, 2010, 2014; Jørgensen et al. 2014; Lenntorp and Hårdh 2009; Larsson and Lenntorp 2004; Roslund 2021; Tornbjerg 1998a, 1998b, 2000; Watt 2011). In general, they have an archaic appearance to them with large wooden hall-buildings placed prominently and centrally at each of the sites. Several large silver or even gold deposits can be found in their vicinity, and in general, they have a more ritualistic find material in combination with imported objects and large productions areas. These include gold foil figurines, weapons, and riding equipment, together with a very high frequency of imported goods urging them to be interpreted as commercial, political, and religious centers. They are characterized by an almost chaotic palimpsest of surrounding settlements with numerous pit-houses and smaller post-built buildings, and often with clear evidence of local production. Despite their





**Figure 1.** Map of southern Scandinavia and sites (Graphic: M.D. Jessen, National Museum of Denmark).

century-long use-phase and pronounced size and wealth, they are all curiously ‘silent’ in the historical sources – we have no contemporary written record mentioning any of them.

The early *emporium* of Haithabu and Birka (together with the early town of Ribe, western Jutland, Denmark) were among the most important Viking Age trading centers in southern

Scandinavia (Ambrosiani 1995; Arbman 1939; von Carnap-Bornheim and Hilberg 2007; Hedenstierna-Jonson 2012; Hilberg 2009, 2020, 2022; Kalmring 2020). The former is situated near the modern German city of Schleswig, at the head of a narrow, navigable fjord known as the Schlei, which provided seafarers with a connection to the Baltic Sea and land-based travel to the Continent. The latter is located on the

small island of Björkö in Lake Mälaren, 30 kilometers west of Stockholm, Sweden, where it attracted traders and craftsmen from a large area and formed a link to the Baltic areas, the Russian rivers, and large trade hubs such as Staraja Ladoga and Novgorod. As such, these sites appear as easily accessible multicultural hot-spots for trade and knowledge-sharing, not least for the continental Christian mission targeting exactly these sites.

## The analyzed material

During the excavations of the aristocratic residence at Tissø, together with fragments of continental drinking glasses, glass beads, and bead-making waste, five fragments of window glass were found. Fragments of windowpanes have also been recovered at several of the other pre-Christian cult sites. More than 20 pieces of window glass have been found at Sorte Muld on Bornholm. During the excavations at Uppåkra three fragments of window glass were retrieved, and four fragments have been registered from Strøby Toftegård.

At Viking Age Haithabu 15 brown and 10 light green pieces of window glass were found during the excavations in the 1990s (Stepphun 1998), as well as a larger number of unpublished examples from previous excavations (Figure 2). At Birka, 81 fragments of window glass have been recorded, many of which were found during the excavations of the harbour area (Danielsson 1973). From Björn Ambrosiani's excavation at Birka (1990-1998) more than 200 fragments of windowpanes were found. A large part of these was found outside the gable of a wooden building from phase 7 and later (*i.e.* of the 10<sup>th</sup> century, see Gaut 2011, 227), and small fragments of window glass have also been found in three graves at Birka, which led Arbman to suggest that these may have functioned as amulets (Arbman 1937, 35, grave Bj 124, Bj 348, and Bj 557).<sup>1</sup>

Importantly, very abrupt endings characterise these localities, wherefore finds from the early medieval period (post-1050) are excessively rare, and a distinct decrease in activities beginning in the first decades of the second millennium is easily

recognised. Accordingly, the settlements are best described as disbanded before 1050 (Ambrosiani 1995; Brandt, Müller-Wille and Radke 2002; Jørgensen 2009, 2014; Lenntorp and Hårdh 2009; Larsson and Lenntorp 2004; Tornbjerg 2000; Watt 2011). For that reason, the finding of several fragments of plane glass becomes conspicuous because the traditional threshold for the introduction of more regular glassed windows has been set in connection with the main wave of building of the Danish rural parish churches from around 1100 (Johannsen 1982).

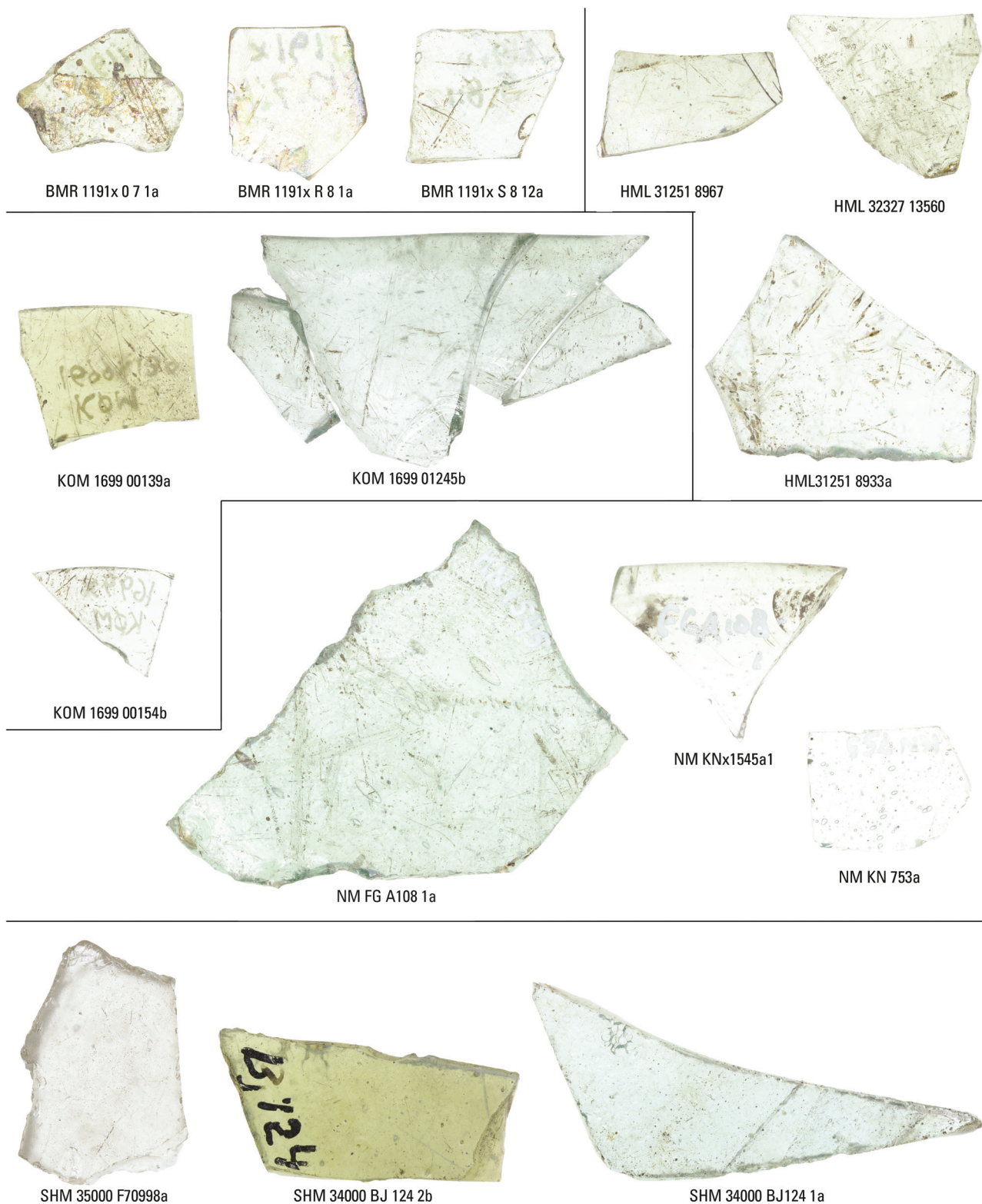
So, what are these glass fragments doing on sites earlier than the assumed introduction of windows? One possibility is the contamination of later debris whereof glass could form part, but as mentioned very little in the find material indicates any kind of later influx nor primary activities taking place after 1050. The use of glass as raw material is also possible, for example for the production of beads as can be seen at Haithabu and Birka, but the more classical settlement sites (*i.e.* Tissø, Strøby Toftegård, Sorte Muld, and partly Uppåkra) only show very limited evidence for the local reuse of glass.

Another route to follow is the possibility that in the Viking Age (or even earlier) the find-rich sites here investigated already saw the use of glassed windows. Taking into consideration that these sites have a significant amount of imported goods (measured in the hundreds) from the Continent or of insular provenience, where glassed windows were a regular occurrence, why would the concept of placing glass in windows not have reached southern Scandinavian's aristocratic sites as well? Not least the spectacular and ritualized hall-buildings found on the aristocratic sites already characterized by extraordinary and exotic architectural features seem obvious candidates for the implementation of windows, and here represented by Strøby Toftegård, Uppåkra, Sorte Muld, and Tissø (Figure 3). We already know that special care was taken to have these large, monumental buildings appear unique, such as whitewashing the daubed walls (Bican 2018; Holst and Henriksen 2015) or occupying prominent positions in the landscape providing them with important signal value and making them visible from a considerable distance

## Haithabu



**Figure 2.** Fragments of windowpanes from Haithabu (Illustration: C.S. Andersen, Moesgaard Museum/Museum für Archäologie Schloss Gottorf) M: 2:1.



**Figure 3.** Examples of windowpanes from all the remaining sampled sites. BMR = Sorte Muld; HML = Uppåkra; KOM = Strøby Toftegård; NM = Tissø; SHM = Birka (Illustration: C.S. Andersen, Moesgaard Museum/T. Sode) M: 2:1.

Glass-groups/ sites	Number of samples	Recycled or reused natron glass				Wood-ash glass	Woodash lime glass		
		Egypt 2	Foy 2 (Egypt)	3.2 (Egypt)	Levant		High CaO/K <sub>2</sub> O ratio	Low CaO/K <sub>2</sub> O ratio, negative correlation K-Na	Low CaO/K <sub>2</sub> O ratio, positive correlation K-Na
Glass-sub-groups	62								
<b>Haithabu (Germany)</b>	31					30	1		
<b>Birka (Sweden)</b>	9	4		1	1	2		1	
<b>Uppåkra (Sweden)</b>	3							1	2
<b>Sorte Muld (Denmark)</b>	3						1	2	
<b>Tissø (Denmark)</b>	11		5				2	3	1
<b>Strøby Toftegård (Denmark)</b>	4						1		3

**Table 1.** Sites, numbers of samples, and distribution of types of glass.

(Jessen 2011; Jessen and Terkildsen 2016). Would glass windows in these exceptional building not be a worthwhile consideration?

To better understand the characteristics of the rather numerous finds of fragments of windowpanes, the assemblages were compared and analysed at a chemical level – an analysis that potentially would reveal the place of production, the function of the glass, and to a large extent also the dating of the glass.

## Analysis and method

All the glass fragments were analysed at the French research laboratory Centre Ernest-Babelon, Institut de Recherche sur les Archéomatériaux, CNRS/University of Orléans, France.

## Analysed corpus

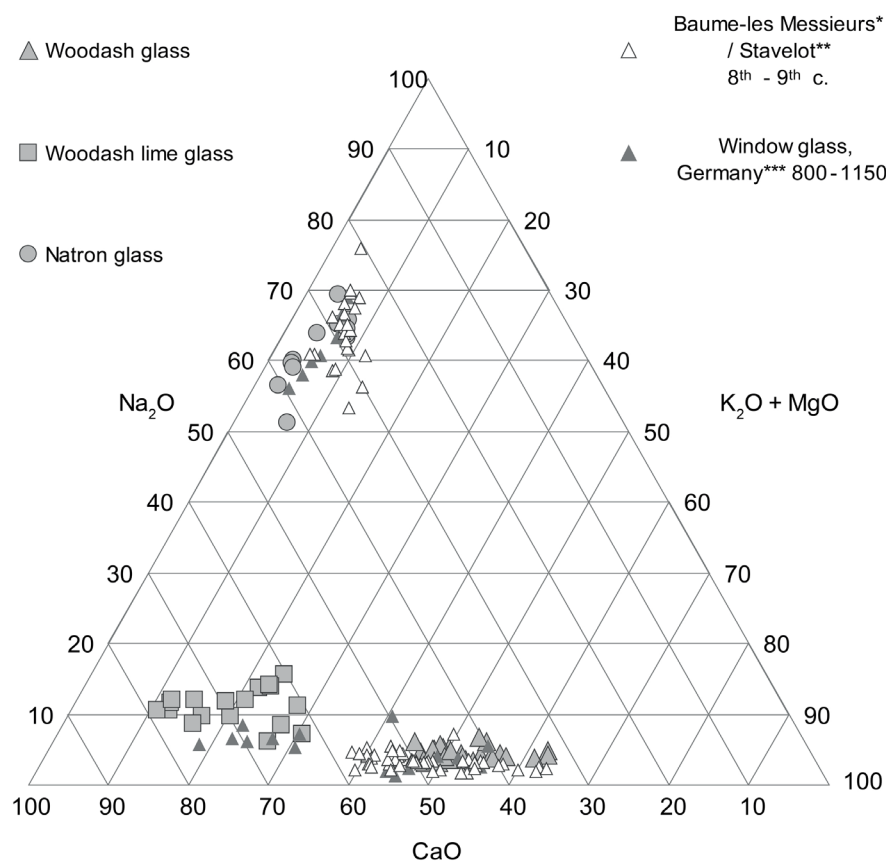
A total of 61 fragments of window glass were analysed, originating from six different sites and dated between the 9<sup>th</sup> and 11<sup>th</sup> centuries (see below), in Germany (Haithabu), Sweden (Birka and Uppåkra), and Denmark (Tissø, Sorte Muld, and Strøby Toftegård). The sample corpus was chosen on the basis of accessible glass fragments in combination with a wish to cover both the large aristocratic sites as well as the early emporium-type settlements (see Table 1). An initial visual evaluation of the fragments was carried out by T. Sode in order to select fragments suitable for chemical analysis. Except for Birka and Sorte Muld, the analysis covered the totality of available window glass from the included sites.

## Analytical method

The analyses of the window glass were carried out by Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). The instrumentation consisted of a Resolution M50E UV laser probe from Resonetics/ASI (Excimer ArF laser working at 193 nm equipped with the S155 cell) coupled with a Thermo Fisher Scientific ELEMENT XR mass spectrometer (Gratuze 2016). LA-ICP-MS allows a nearly non-destructive analysis, invisible to the naked eye, of the glass objects. Analytical parameters were as follows: the excimer laser was operated at 5.5 mJ with a repetition rate of 10 Hz, ablation time was set to 50 seconds: 20 seconds pre-ablation, so that contamination could be removed, and 30 seconds collection time corresponding to 9 mass scans from lithium to uranium. The signal was measured in counts/second, in a low-resolution mode for 58 different isotopes. These 58 elements include all major, minor (except sulphur), and trace elements which are usually present in glass samples (Gratuze 2016). Blanks were run periodically between a series of

20 samples. Spot sizes were set to 100  $\mu\text{m}$  (although reduced down to 70  $\mu\text{m}$  when saturation occurred for an element such as manganese). During analysis live counts were continuously observed: when element spikes signifying the presence of inclusions were observed, results were discarded, and a new area was selected. From one to three areas were analysed per sample; homogeneity and agreement between runs were consistently good.

Calibration was performed using five reference glass-standards: NIST610, Corning B, C, and D, and APL1 (an in-house reference glass used for chlorine determination), which 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. The measured values were normalised against  $^{28}\text{Si}$ , the internal standard. Concentrations are calculated assuming that the sum of the concentrations of the measured elements is equal to 100 weight percent. For the major and minor elements, accuracy and precision were within 5 % relative and within 10 % for most trace elements.



**Table 2.** The distribution of principal fluxes constituents shows three clusters.



## Results

According to the principal constituents brought by the fluxes ( $\text{Na}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$ , and  $\text{CaO}$ ), the results obtained enable the classification of the 61 analysed window glass fragments into three main compositional groups (Table 2).

The first group consists of 11 glasses made with natron. Five of these originate from Tissø (Denmark) and the six others from Birka (Sweden). The characteristics of the glasses from both sites appear different.

The second group contains 32 glasses made with woodash, containing similar amounts of lime and potash ( $0.71 < \text{CaO}/\text{K}_2\text{O} < 1.69$ ). It consists of 30 of the 31 Haithabu glasses and 2 Birka glasses. This group will be further referred to as the woodash glass group (Table 3).

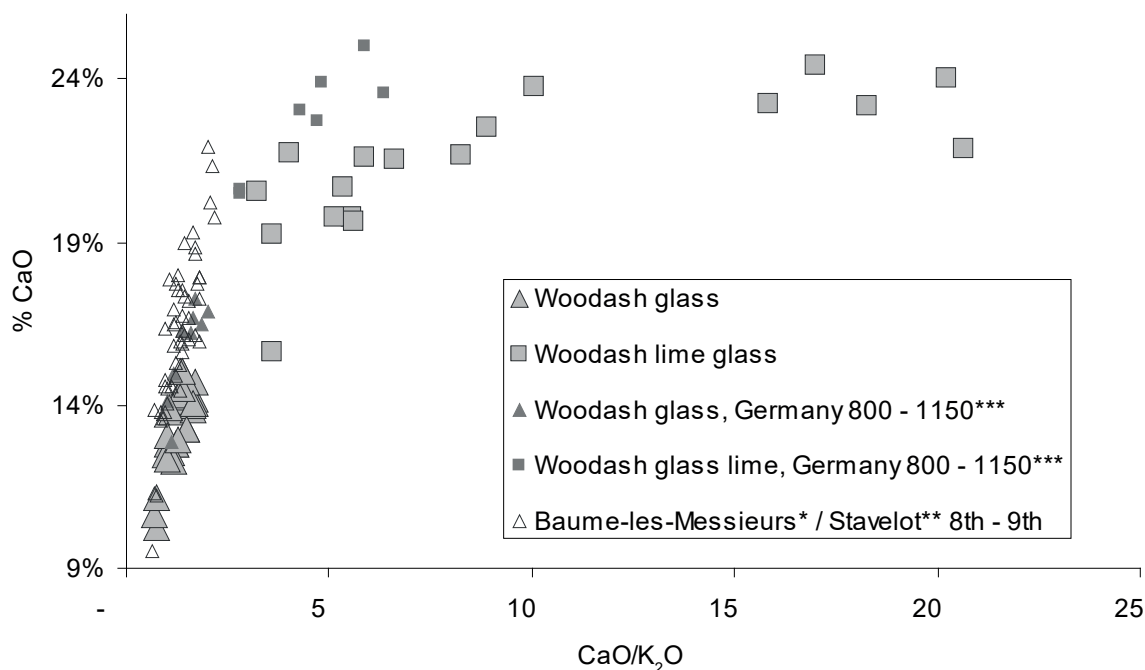
The third and last group consists of the 18 remaining glasses, made with woodash containing more lime than potash ( $3.25 < \text{CaO}/\text{K}_2\text{O} < 20.7$ ). We find in this group 1 Haithabu glass, 1 Birka glass, 3 Uppåkra glass, 6 Tissø glass, 3 Sorte Muld glass, and 4 glass from Strøby Toftegård. According to the value of their  $\text{CaO}/\text{K}_2\text{O}$  ratio, the glass

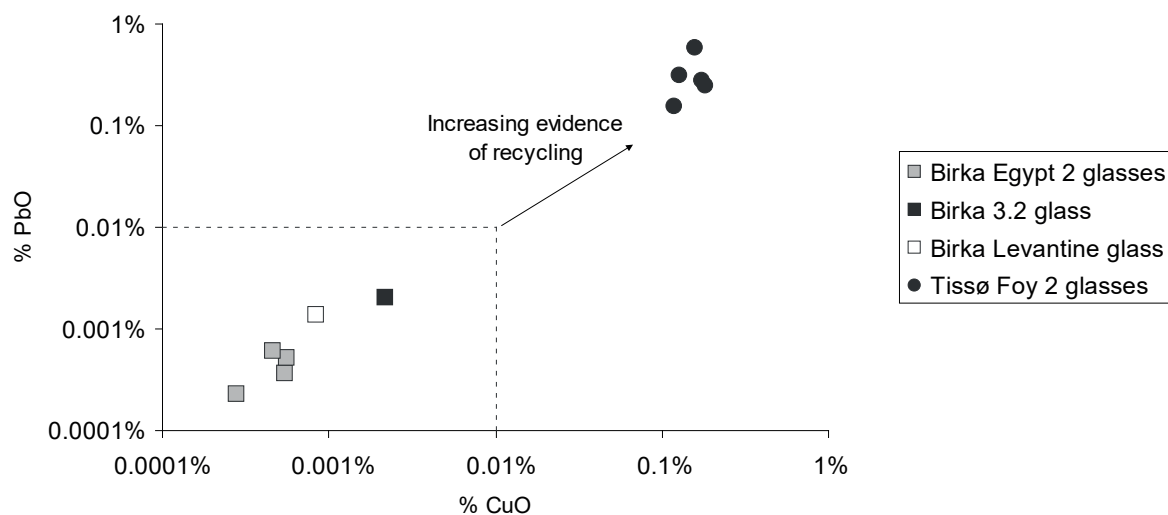
of this group can be further subdivided into two main subgroups. On one side 13 glasses with  $\text{CaO}/\text{K}_2\text{O} < 11.7$  and on the other side 5 glasses with  $\text{CaO}/\text{K}_2\text{O} > 15.8$ . These 18 window glass fragments will be further referred to as the woodash-lime glass group.

### The natron glasses

All glass from this group is soda-lime glass ( $13.1 < \% \text{Na}_2\text{O} < 18.1$  and  $6.9 < \% \text{CaO} < 9.5$ ) characterized by low contents of magnesia ( $\text{MgO} < 0.92\%$ ), potash ( $\text{K}_2\text{O} < 1.22\%$ ) and phosphorus pentoxide ( $\text{P}_2\text{O}_5 < 0.19\%$ ). They share all the characteristics of Near Eastern glasses (Egypt and Levant) produced after the 5<sup>th</sup> century (Ceglia et al. 2015; Cholakova et al. 2016; Foy et al. 2003; Freestone et al. 2018). Window glass of this composition has also been found at Baume-les-Messieurs in France (van Wersch et al. 2016), at Stavelot in Belgium (van Wersch et al. 2014), and Corvey in Germany (Wedepohl 1997, 2000, 2001; Wedepohl et al. 2010).

At Tissø, according to their contents in metallic elements (Table 4), such as copper ( $0.12 < \% \text{CuO} < 0.18$ ), tin ( $0.03 < \% \text{SnO}_2 < 0.08$ ), and lead





**Table 4.** Metallic elements in the Tissø and Birka samples.

( $0.15 < \% \text{PbO} < 0.59$ ), the five natron glasses can be classified as highly recycled glasses. They contain also high contents of manganese ( $0.59 < \% \text{MnO} < 0.86$ ), antimony ( $0.17 < \% \text{Sb}_2\text{O}_3 < 0.25$ ), titanium ( $0.12 < \% \text{TiO}_2 < 0.13$ ), and zirconium ( $99 < \text{ppm ZrO}_2 < 104$ ), which is characteristic of the Egyptian Foy 2 glass group produced during the 5<sup>th</sup> and 6<sup>th</sup> century (Foy et al. 2003; Schibille et al. 2016).

At Birka four of the six glasses belong to the Egypt 2 glass group (Schibille et al. 2019). Their soda contents suggest that two of them ( $\text{Na}_2\text{O} > 15.2\%$ ) may have been produced before 815 and the two other pieces ( $\text{Na}_2\text{O} < 14.3\%$ ) after this date. None of these glasses show evidence of recycling. Among the two last glass fragments from Birka, we have one Egyptian glass belonging to the group Foy 3.2 (produced mainly in the 5<sup>th</sup> century) and one later Levantine glass (Foy et al. 2003; Rosenow and Rehren 2018; Schibille et al. 2016). Here again, there is no evidence of recycling in these glasses.

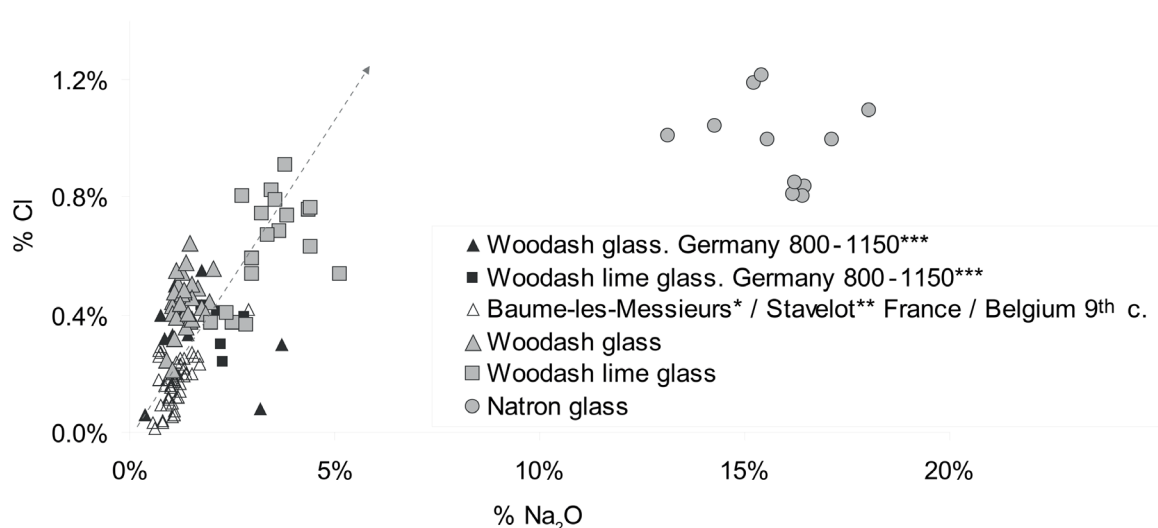
### **The woodash glasses**

This large group of glass is probably the most frequently encountered among window glass dated between the end of the 8<sup>th</sup> century and the 12<sup>th</sup> century. Glass of this composition has been identified at Baume-les-Messieurs in France (van Wersch

et al. 2016), at Stavelot in Belgium (van Wersch et al. 2014), and several German sites: Paderborn, Höxter, Corvey, Drudewenshusen, Bruns- hausen, and Lorsch (Wedepohl 1997, 2000, 2001; Wedepohl et al. 2010). Currently, no subgroup correlated with chronology or provenance can be identified in this large group which shows, however, an important variability for most of its minor oxide components (Table 5). All these glasses were most probably produced in northwestern European glass workshops from the end of the 8<sup>th</sup> century and after.

### **The woodash-lime glasses**

Probably, glasses from this group originate from northern Europe too, albeit from a different geographical area than those of the previous woodash glass group. The main difference between the two groups lies in their  $\text{CaO}/\text{K}_2\text{O}$  ratios, in the contents of some components of the fluxing agent, and in some trace elements (Table 5). Woodash-lime glasses contain two and a half times more soda than woodash glasses. As shown by Wedepohl, woodash-lime glass requires a higher amount of soda because its low potassium concentration needs to be supplemented by the addition of sodium chloride (Gerth et al. 1998). For the period in question, one could also hypothesize that soda was mixed into the glass batch by adding a natron glass



**Table 5.** Sodium oxide and chlorine content.

cullet. However, if we plot the contents of sodium oxide and chlorine for natron, woodash, and woodash-lime glasses, it appears that the chlorine contents of the two latter are too high to be correlated with the average chlorine content of natron glass.

It seems therefore that glassworkers were probably adding sodium chloride directly to their glass batch for both woodash and woodash-lime glasses. Woodash-lime glasses also contain more alumina and less magnesia than woodash glasses.

As mentioned above, this glass group is more heterogeneous than the woodash glass group. Five of these glasses have high  $\text{CaO}/\text{K}_2\text{O}$  ( $> 15.8$ ) ratios while the 13 others have lower  $\text{CaO}/\text{K}_2\text{O}$  ratios ( $< 11.7$ ), which are in the same range as those determined by Wedepohl on German window glass. The distribution of these 13 glasses as a function of their soda and potash contents shows two different trends.

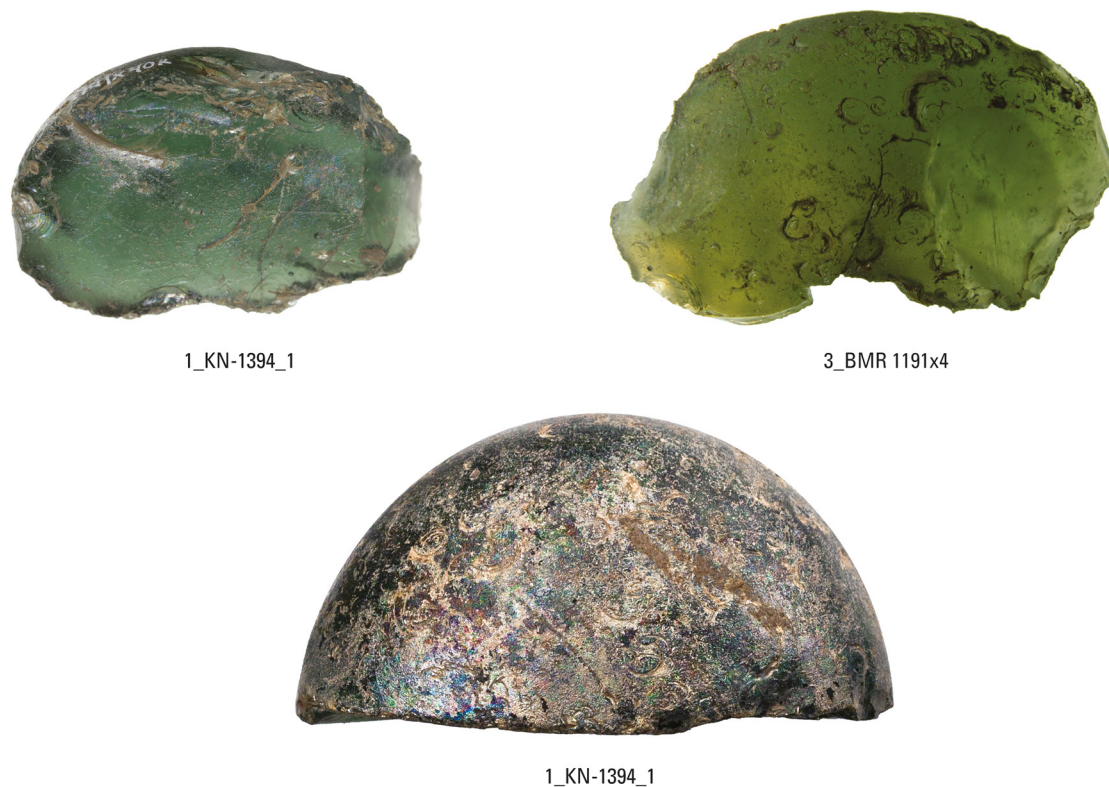
Firstly, soda and potash are negatively correlated, soda contents increase while potash contents decrease. Secondly, both types of oxides are positively correlated and increase together. We can thus distinguish three subgroups which contain respectively:

Five finds from Haithabu (1), Tissø (2), Sorte Muld (1), and Strøby Toftegård (1) have high  $\text{CaO}/\text{K}_2\text{O}$  ratios ( $> 15.8$ ).

Six finds from Birka (1), Uppåkra (1), Tissø (2), and Sorte Muld (2) have low  $\text{CaO}/\text{K}_2\text{O}$  ratios ( $< 11.7$ ) and negatively correlated potash and soda contents.

Seven finds from Uppåkra (2), Tissø (2), and Strøby Toftegård (3) have low  $\text{CaO}/\text{K}_2\text{O}$  ( $< 11.7$ ) ratios and positively correlated potash and soda contents.

We observe that window glass from these different subgroups is not characteristic of a particular archaeological site but is unevenly distributed among the different sites. It, therefore, seems more likely that these different types of glass were produced and used during the same period rather than successively at different times. They most probably characterise the variability of the composition of woodash glasses produced during the same period, rather than an evolution of their compositions over time. This hypothesis is reinforced by the presence at Tissø and Sorte Muld of three glass smoothers with compositions very similar to those of the window glass of this group (Figure 4). These three smoothers have low  $\text{CaO}/\text{K}_2\text{O}$  ratios and have negatively correlated potash and soda contents for two of them (Tissø NM KN 728 and Sorte Muld 1191X40) and positively correlated potash and soda contents for the last one (Tissø NM KN 1394). The association of these types of glass, within the different studied sites, could also suggest the existence, during this



**Figure 4.** Fragments of glass smoothers from Tissø and Sorte Muld (Illustration: C.S. Andersen, Moesgaard Museum/ M.D. Jessen and T. Sode) M: 1:1.

period, of a single and relatively centralised production and supply system for window glass and glass smoothers. This may also reflect the relative contemporaneity of the finds from these sites.

### ***Comparison with contemporary European early medieval window glass***

According to Wedepohl, the production of wood-based plant-ash glass in northwestern Europe can be divided into three main phases (Wedepohl 1997, 2000, 2007).

From 800 to 1000-1050, using window glass and vessels originating from Paderborn, Höxter, Corvey, Drudewenshusen, Brunshausen, and Lorsch, he defined a group named early woodash glass. It contains potash lime glass, with a highly variable proportion of lime and potash, their CaO/K<sub>2</sub>O ratios varying between 1.0 and 6.4. These glasses could be defined as the precursor of future woodash and woodash-lime glass. On most of the Carolingian and post-Carolingian sites, these

early woodash glasses are found associated with recycled Near-Eastern natron glasses (either of Roman, early medieval, or Islamic origin).

Then, between 1000 and 1400, using glasses originating from the German monasteries and towns of Corvey, Höxter, Brunshausen-Gandersheim, and the glassworks of Steimcke in the Bramwald Mountains, he defined another group of woodash glass. These glasses are all potash-lime glasses containing analogous amounts of lime and potash. Their CaO/K<sub>2</sub>O ratios vary between 0.5 and 1.6, thus indicating a more controlled and skilful mode of production.

The last phase began around 1300. For Wedepohl, who mainly defines woodash lime glass based on vessel fragments from Höxter (1370 to 1500) and the Eichsfeld glassworks (1400 to 1600), the 14<sup>th</sup> century is the period when the manufacturing processes for woodash lime glass were finalised and standardised. This glass also known as HLLA glass, for High Lime Low Alkali, contains a large amount of lime (CaO > 20 %) and has high

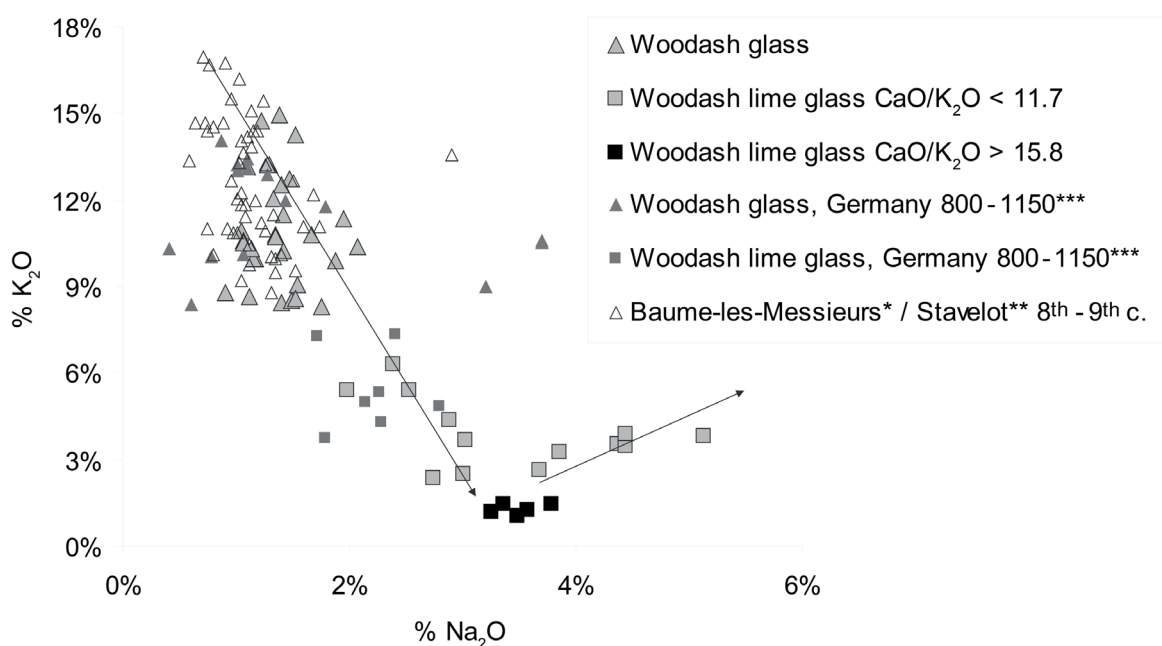
CaO/K<sub>2</sub>O ratios (from 1.6 to 8.0 with an average value between 4.0 and 5.0). Studies on architectural glass show that from the 14<sup>th</sup> century onwards, it was the main type of glass used for stained glass and windowpanes (Schalm et al. 2005, 2007).

However, in our studied corpus, some of the woodash-lime glasses from Denmark (Tissø 3 and Sorte Muld 2) and Sweden (Birka 1 and Uppåkra 1) are fairly similar to both the early woodash glasses analysed by Wedepohl (Table 6) and to some woodash-lime glass smoothers, while others show different characteristics: either higher CaO/K<sub>2</sub>O ratios or positively correlated soda and potash contents. According to literature values, all the woodash-lime or HLLA glasses produced from 1300 have a CaO/K<sub>2</sub>O-ratio lower than 8 (Schalm et al. 2005, 2007; Wedepohl 1997). Thus, most of the glasses analysed here do not correspond to the strict definition of HLLA glasses, their characteristics (composition and CaO/K<sub>2</sub>O ratio) seem to correspond rather to the early woodash glass defined by Wedepohl (Wedepohl 1997). The presence of recycled or reused natron glasses, at Tissø and Birka, reinforces this hypothesis. It is thus highly probable that these windowpanes were used between the beginning of the 9<sup>th</sup> and the end of the 11<sup>th</sup> centuries.

At Birka (Sweden), all the early woodash-lime glasses are found associated with Egypt 2 natron glasses and woodash glasses, similar to those found at Haithabu (Germany). At the Danish sites (Tissø, Sorte Muld, Strøby Toftegård) and at Uppåkra (Sweden), the early woodash-lime glasses are similar to those found at Birka and Haithabu. At Tissø (Denmark), the woodash-lime glasses are also found associated with highly recycled Foy 2 natron glass.

Foy 2 natron glasses were produced in Egypt between the 5<sup>th</sup> and 6<sup>th</sup> centuries but are continuously found in large amounts in western Europe until the 11<sup>th</sup> century (Foy et al. 2003). Egypt 2 natron glasses were probably produced in Egypt during the 9<sup>th</sup> century (Schibille et al. 2019). Although glasses from this group have spread outside Egypt to a lesser extent than the Foy 2 glasses, they are occasionally found in Europe until the 11<sup>th</sup> century.

Among our corpus, Haithabu and to a lesser extent Birka show a fairly distinct distribution of the glass types. In Haithabu we have a clear majority of woodash glass, while in Birka we find mainly reused natron glass and woodash glass. At the four other sites (Uppåkra, Sorte Muld, Tissø, Strøby Toftegård), we have a majority of woodash-lime glass which is associated with reused natron glass



**Table 6.** Trends in distribution as a function of soda and potash contents.

at Tissø. The fact that the different types of wood-ash-lime glass are found randomly associated at these four last sites could suggest that they are more or less contemporary and that they could be associated with the same supply network, different from the one that supplied Haithabu and Birka. According to Wedepohl's chronology, it means that the woodash-lime glass fragments studied here were certainly produced before the 13<sup>th</sup> century and do not exclude that they may, based on his glass chronology, all belong to occupation phases dated between the 9<sup>th</sup> and the 11<sup>th</sup> centuries. However, we must also consider that the number of glasses analysed for each site is relatively small and probably only gives a partial picture of the potential variability of the compositions of the glasses used. In order to identify the production and distribution networks of windowpanes during that period, a more extensive study of Scandinavian glass finds should be carried out.

The identification of finds of window glass at pre-Christian cult sites in Scandinavia appears to be too numerous to be merely coincidental. It was previously assumed that the earliest window glass in Scandinavia was used in the construction of churches during the Middle Ages. It was also thought that windows with glass panes did not become common in the buildings of the king and nobility until the Middle Ages. Even though windowpanes were not common, this does not necessarily mean that they were not used as early as in the elite residences of the Viking Age and pre-Christian temple buildings. Could the lack of windowpanes amongst pre-Christian finds in Scandinavia simply be a misinterpretation of finds of early plane glass because it was just presumed that this was window glass of a more recent date? It is therefore thought-provoking that fragments of window glass are found both at pre-Christian cult sites (where there was no intensive production of glass beads), as well as at the trading centres of the Viking Age as shown in the study, Haithabu and Birka, as well as Ribe (see Barfod et al. 2022 for a thorough analysis of both raw material and bead production processes at the Ribe glass workshops). Why are fragments of window glass found at the elite sites, long before it is thought that glass panes are archaeologically and historically represented? Why is window

glass associated with the residences of magnates at Tissø, Strøby Toftegård, Uppåkra, and Sorte Muld, which are all located in areas where window glass was not previously regarded as having been utilised in buildings until modern times?

## The evolution of windowpanes

From the beginning of the 1<sup>st</sup> century, glass panes were made in the Near East and at Roman glassworks in Europe. Early windows containing glass are known from excavations in Rome, and at Pompeii and Herculaneum, where they are, for instance, found in public buildings, upper-class homes, greenhouses, and *thermae*. There are also several early Roman buildings with glass windows in Switzerland, France, Germany, and Britain (Balcon et al. 2009; Foy 2005; Harden 1961; Whitehouse 2001). The glass panes were mounted in window frames of wood or metal, which in some cases could be opened to ventilate the buildings.

The earliest window glass in Europe could have been made by placing the red-hot, malleable glass onto a flat, polished marble slab. After this, the glass could be shaped and pulled with various types of tongs and tools of iron; tool marks can often be seen in the corners and along the edges of these so-called cast, square pieces of window glass. These glass panes are always smooth on the top side, and matte and uneven on the back.

In the middle of the 1<sup>st</sup> century at the latest, Roman glass workshops began to produce window glass using the cylinder method (see also Foy 2005). In this technique, the glassmakers began by blowing a large glass cylinder, which was subsequently cut up and folded out on a tabletop – hence the name table glass. This produced a flat piece of glass, which was characterised by a straight, slightly rounded edge, and elongated, parallel blisters in the glass.

The cylinder glass was also matt and uneven on the side that was folded out onto the flat tabletop. Remains of glass panes made using the cylinder method have been recovered from excavations in Rome, Pompeii, and Herculaneum. In Europe, in both Antiquity and the Middle Ages, this was

the most widely used method for making glass panes, and window glass made by using the cylinder method was common until the end of the 19<sup>th</sup> century. In the 1950s, the British archaeologist and glass specialist Donald B. Harden examined and analysed a large number of finds of Roman window glass from Britain, which were described as cast, although he proposed that they may have been made as cylinder glass (Harden 1961).

The third type of window glass, the crown glass, involved the production of round glass discs of variable diameter. This method apparently originated in the eastern Mediterranean during the 1<sup>st</sup> century, where small, flat, round glass panes measuring between 8 and 25 cm in diameter were made. These round glass panes were often mounted in pairs in cast plaster windows. Archaeological finds of crown glass dating at the latest from the 4<sup>th</sup> century have also been made in Italy, France, Germany, and Britain. However, it seems that it was not until coloured glass was produced for mosaic panes in church buildings, that window glass made by using the crown glass method became common in western Europe. During the Middle Ages, crown glass with a diameter of up to 1.5 m could be made. Crown glass is characterised by a curved, slightly thickened, rounded edge and concentric blisters and impurities in the glass itself. After cooling, the glass disc is divided into two halves – hence the nick-name half-moon glass. These halves were subsequently cut into smaller pieces, which were then fitted into the leaded windows. There was a thickening of the glass disc in the centre, where the glassmaker's puntel was placed. When the finished crown glass was knocked off the puntel, the puntel mark was left behind, which was popularly known as a bullseye. This bullseye was regarded as waste glass but was in historical times often used in round or oval door windows. Crown glass panes always have smooth and shiny surfaces on both sides (*idem*, see Foy 2005).

### **Illumination for God and for King**

Glass windows are found in the earliest Christian churches dating from the beginning of the 4<sup>th</sup> century when, for instance, churches were

built in Rome and Ravenna. In 540, Ravenna was conquered by the Eastern Roman emperor Justinian I (482-565) and direct relations with the Christian, Byzantine Empire lasted for several centuries; close cultural connections were also established, involving Eastern Roman glass-making and architecture. During the reconstruction of the dome of the Hagia Sophia cathedral in Constantinople, which had collapsed due to an earthquake in 558, Emperor Justinian had a new dome constructed with 40 large glass windows. These windows were placed all around the base of the dome so that the sun's rays could be reflected off the golden glass mosaics inside the church (Trowbridge 1930).

Archaeological excavations of the Cathedral of Santa Maria Assunta on the island of Torcello, in the lagoon just north of Venice, uncovered a glass workshop dating to the 7<sup>th</sup> century, which produced both window glass and glass tesserae (Leciejewicz et al. 1977).

During investigations of the monastery of San Vincenzo al Volturno in Italy, several workshops associated with the monastery's private quarters were excavated, including glassworks with remains of glass furnaces, along with crucible fragments and production waste. The finds included green panes in various shades made by using the cylinder method and coloured panes of crown glass. A glazier's workshop for the preparation of window glass was also identified in the workshop areas. Here, H-shaped lead comes and cut-out blue panes were recovered, showing that leaded windows had been produced. The workshops operated during three phases, from the early 9<sup>th</sup> to the 11<sup>th</sup> century (Balzer 1999; Moreland 1985).

Early Roman windows have also been found, with the cut panes held together by various types of lead strips, but it seems that it is not until the 8<sup>th</sup> century that H-shaped lead comes started to be used in the assembly of glass mosaic windows. The use of H-shaped lead comes became common during the 9<sup>th</sup> century and examples are known from Italy, France, Germany, and Britain (Whitehouse 2001). At the abbey of Saint-Denis, north of Paris, limestone moulds for making H-shaped lead comes,

dating to the Carolingian period, have been found (Balzer 1999).

In Britain, glass panes are present in both Roman and Anglo-Saxon buildings (West 1931). Archaeological excavations, however, indicate that window glass is only rarely found in the centuries after the collapse of the Western Roman Empire, and there is no evidence that glass windows were found in the buildings of Britain or northern Europe at this time. The earliest archaeological discoveries of glass furnaces from Anglo-Saxon England date to the late 7<sup>th</sup> century, when Bishop Benedict had a stone church and monastery erected in Wearmouth, in the Anglo-Saxon kingdom of Northumbria in northern England. Contemporary written sources indicate that in the year 675 Benedict had French glassmakers brought in to produce windows for the church, the cloister, and the monastery refectory (Harden 1961; Trowbridge 1930). In 688, the West Saxon king Ine established the abbey at Glastonbury. Here, the remains of four glass furnaces have been excavated, where window glass was produced using cylinder methods (Bayley 2000; Evison 2000; Willmott and Welham 2013).

During the archaeological excavations of the monastery at Fulda, which was established in 744, glass was found, which had been made by melting together Roman natron glass and European potash glass. Similar mixed glass was also retrieved at Lorsch Abbey from the Carolingian period, as well as at the Viking Age emporium of Haithabu (Kronz, Hilberg, Simon and Wedepohl 2015, 39 ff.). At some point in the 12<sup>th</sup> century, western European glassworks apparently stopped using natron glass.

The written sources and archaeological excavations both show that window glass is only rarely found in the period after the collapse of the Western Roman Empire. Even if there are glass windows present from 5-6<sup>th</sup> century France, there may have been a loss of technological knowledge (as was the case with the manufacture of cement and the construction of brick-built houses), and a decline in the need for glass windows caused by changes in building traditions. During the 8<sup>th</sup> century, however, there was a significant change in western

European glass technology. Increased demand for window glass, especially for churches but likewise for large aristocratic buildings, apparently led to the development and production of potash glass in Europe, with potash in the form of woodash (potassium) used as a flux instead of natron (soda) (Wedepohl, Winkelmann and Hartmann 1997). Various types of early potash glass are known, depending on where in Europe they were made. This early potash glass was often very unstable. Most early church windows consist of varying light, greenish-coloured potash glass, where the colouration was caused by the iron oxide naturally present in the sand used for making the glass. Some coloured window glass was, however, made from melted-down Roman natron glass (van Wersch et al. 2014). The monk Theophilus Presbyter writes in *De Diversis Artibus* around 1100 how glass can be made from beech woodash, but also that blue window glass can be produced by melting down old Roman glass. In addition, he describes the making of stained-glass mosaic windows with lead comes (Theophilus 1979).

A similar development can be seen in the use of glassed windows in the aristocratic and royal palaces of the Continent. Particularly so for the early Carolingian representational *Aula Regia* that not only incorporated, mimicked, and developed ecclesiastical architecture but also were placed in close vicinity – as a sort of twin building – to the large basilicas and chapels of the Continental palaces. During the Carolingian period, these *pfalzen* more or less filled the same function and were almost all physical extensions of earlier Merovingian *villae*, thus continuing the traditions of both the Roman and Merovingian courts where kingly and churchly obligations were tightly interrelated (Wamers 2017, 150-152). In that sense, the house of God and the house of the King made use of very similar physical expression and symbolic architecture, and among these the use of glassed windows and coloured light figured prominently. The main *pfalz* of Charlemagne, found in Aachen, even has clear archaeological traces from local production of glass at the exact same location where the chapel and *Aula Regia* can be found (Giertz and Ristow 2013; Ristow 2016). Accordingly, since the same persons or families controlled both royal as well



as ecclesiastical construction works, at least from the late 8<sup>th</sup> century onward the aristocratic seats of the Continent would have had access to and most likely used glassed windows in their palaces. A telling example of the coupling between aristocracy, technological knowledge and glass windows can be found in *The Lives of The Holy Abbots of Weremouth and Jarrow*, by the venerable Bede. He mentions that (sometime after 674) Bishop Benedict sent message to Gaul (*i.e.* the Merovingian kingdom) to fetch makers of glass so that they could help with the finishing touches of his church and "... they might glaze the windows of his church ..." (Bede, chapter 5, after Giles 1910). This bears witness to the detailed knowledge about how to manufacture and use glass held by the continental craftsmen.

### The situation in southern Scandinavia

In almost all excavations of the Danish parish churches, remains of window glass, which is often painted, have been found, and the conspicuous use of special light and windows can also be observed already in the earliest Danish church buildings (Hansen 1974, see also Melin 2022 for a thorough examination). Here, it is important to point out that this also applies to the wooden churches, and it is not a phenomenon that was only introduced with the stone buildings. The reused stave planks found in Framlev Church (*Danmarks Kirker*, Framlev Kirke) can, for example, be mentioned in this respect; here, window sections from an earlier stave-built structure were reused in the ensuing stone-built church.

Unfortunately, the wood could not be dated<sup>2</sup>, but as the existing stone church was built around 1100, the plank must have belonged to a building from the later Viking Age or the very early Middle Ages – church or profane building. Grooves and tongues from the mortising into the wooden wall are still preserved on the best-preserved plank, and the plank has then been secondarily cut around the window section. Inside the window groove, small nails are still preserved, which held the window section in place, and was assembled with lead comes (Grinder-Hansen 2009; Koch 1898). The curved window opening measures *c.*85 x 35 cm,

and the windows were therefore quite large; these could both provide a significant amount of light, and it would also have been possible to insert quite large and detailed sections with leaded glass panes. There is also a similar find from Dybe Church, a preserved stave plank (dendrochronologically dated to the last decade of the 11<sup>th</sup> century) with a cut-out rounded arch with grooves for holding the lead-framed glass window (*Danmarks Kirker*, Dybe Kirke). Importantly, this mounting technique, which can be observed on both the Framlev and Dybe planks, could very easily have been used in all types of timbered buildings and therefore may stretch way back in time.

At Lilleborg on Bornholm, which was a royal castle from around 1190 and is believed to have been destroyed in 1259, fragments of glass panes and glass mounted in H-shaped lead comes have been found, as is the case at other early royal Danish castles. This underlines the fact that also the earliest profane, stone-built structures in Scandinavia, such as Lilleborg, made use of the newest technology available for installing glassed windows. Obviously, exchange between building categories is inevitable and has been for millennia, and telling the individual parts apart is virtually impossible – not least with regard to (fragments of) windows (Qvisttröm 2020, 247 ff.).

In a similar vein, the exchange (or inspiration) across borders is just as frequent a phenomenon. For example, the organisation of the buildings as it can be seen during the Fugledegård-phase at Tissø (*c.*800-1050), might quite well rest on the concept of Carolingian manorialism. Here, the large hall-building can perhaps be equated with the Carolingian *Aula Regia* mentioned above, whereas the small fenced-in area attached to the hall-building could be a mirroring of the chapel of the *pfalz*. In this way the two buildings would provide room for both representational as well as religious requirements. Encircling the central areas of both types of aristocratic settlements, several secondary buildings connected with production and everyday life can be seen (Jørgensen 2004, 245-247, fig. 7,9, and 16). Kings and magnates were especially important to the missionary activity of the Roman Church, and the presence of temples or cult buildings at the

pre-Christian cult sites demonstrates that it was the elite of the society who were in charge of many of the religious activities.

From the historical sources, we know that Scandinavian royalty, and presumably also other persons from the top echelon of society, visited the Carolingian palaces (for example Harald Halfdansson Klak; Wamers 2017), and here they would have witnessed the large aulas with glassed windows. Imitating the structure of the Carolingian manor would quite possibly also include transferring specific architectural features of the aula, such as glassed windows.

Together with the obvious presence of woodash-lime windowglass at the pre-Christian cult sites, royal residences, and Viking Age trading centres, this could indicate that there were actual glass windows in prominent buildings as early as the Viking Age. Even if the exact contexts are lacking, the finds pattern is also interesting: Were glass panes perhaps used in the hall-buildings and temples of pre-Christian Scandinavia, like they were in contemporary Frankish and Anglo-Saxon palaces and churches?

The glass in the church windows was perceived as a special, magical material, which could let in the sunlight and illuminate the room, whilst also keeping the cold, wind, and rain out, whereas windows in aulas would underline the well-connected and exclusive character of the royalty residing there. This suggests that there possibly were one or more small windows with glass panes in the pagan cult buildings, like in the stave churches and the early stone churches in Jutland, just as the hall-buildings would be illuminated through glassed windows as were the aulas of the continental palaces.

## Discussion

The strikingly large number of fragments of window glass from the pre-Christian cult sites, trading centres of the Viking Age and graves paint an interesting new picture. The finds of this early window glass seem too numerous to be merely coincidental and quite likely, in pre-Christian Scandinavia, windows with glass panes were already used in

Viking Age magnate residences and cult houses in the same way as they were in contemporary Frankish and Anglo-Saxon palaces and churches.

An interesting question is why early northern European woodash-lime glass is found at the pre-Christian cult sites, trading centres and in graves from the Viking Age? Most of these sites are located where archaeologists would not expect to find remains of glass panes. Even though glassed windows were not common, this does not necessarily mean that they were not already used in the magnate residences and temples of the Viking Age. Several other archaeological finds show that the magnates and kings of southern Scandinavia were very much inspired and influenced by fine art and craftsmanship, from both the Frankish, Anglo-Saxon, and Byzantine areas. The present study shows that the notion that there are no glassed windows amongst pre-Christian finds is a result of archaeologists having been misled by their historically biased preconception. Consequently, it has wrongly been presumed that these must be window glass of a more recent date.

Other evidence suggests that glass was regarded as a magical material in the Iron Age and Viking Age. The Elder Edda tells of a magical glass sky (*glerhiminn*), and that stones, placed on an altar, would be turned into glass when they have the blood of sacrificial animals poured over them. In Old Norse literature, it is also stated that glass is a material onto which runes that have a magical effect can be carved (Nyrop 1879, 434). Therefore, it seems reasonable to agree with Arbman's interpretation of the window glass fragments from burials at Birka as amulets.

Veneration of the magical powers of glass can be identified at an earlier date in Scandinavia. It can, for example, be observed in late Roman Iron Age graves, in which small pieces of glass have been placed in the mouths of the deceased instead of a coin presumably intended to pay Charon when crossing the river Styx. This practice suggests that glass was thought to have special value and magical attributes (Boye 2002, 203 ff.). This is such a widespread phenomenon that glass fragments are the most common type of object recorded in the

mouths of the deceased, and are more common than coins, which are found in the original version of this custom in continental graves (Dyhrfeld-Johnsen 2009).

Moreover, glass occupies a special position at an early date in more tangible and use-orientated ways: Iron Age pottery with small fragments of glass inserted in the vessel, the so-called window vessels, also point towards a special and conspicuous use of glass (Oldenburger 2017a, 397-401). Experimental archaeology and the reconstruction of window vessels have clearly shown that these were not just objects for show, but such vessels with an inserted piece of glass would have been waterproof and could be used as drinking cups (Oldenburger 2017b). As such vessel types could function as drinking cups, they obviously were to be displayed and:

many of the window vessels were of types presumably used for serving and drinking liquids during social gatherings. Therefore, they were meant to be seen and could be used to impress guests and visitors by showing that the owner was in possession of glass (Oldenburger 2017a, 401).

In South Scandinavia, the presumably high value of the glass probably also contributed to it being an especially sought-after commodity, which its owner could use to emphasise their own particularly privileged position. Glass is also found purely as a commodity in special contexts, and a piece of melted glass deposited in a posthole at Tietgenbyen, Funen, is an example of the secondary and deliberate ritual use of a glass fragment. This has been interpreted as a type of house offering upon the foundation of a building, which was erected at the transition between the Late Roman and the Early Germanic Iron Age (Lundø 2019).

Besides being used as adornment, glass can also be seen as part of personal equipment as far back as the Late Roman Iron Age. In the Illerup Ådal weapon deposits, glassbeads and even fragments of melted glass have been kept as part of the personal equipment (Ilkjær 1993, 51-52), thus underlining the special status of glass. There is therefore a considerable amount of evidence from Scandinavia

suggesting that glass not only had a potential mercantile value but also was believed to have various magical attributes.

## Concluding remarks

Numerous fragments of plane glass, *i.e.* windowpanes, have been found at several Viking Age sites, but often been overlooked in the research of the period and at large regarded as modern waste. However, the distribution and composition of the analysed corpus indicate two different approaches to the acquisition of windowpanes. In the proto-urban settings at Birka and to some extent also Haithabu, the imported glass has a recognisable oriental/Egyptian fingerprint, while the pre-Christian cult-sites of southern Scandinavia mainly show continental origins. To some extent the latter finds can be classified as belonging to more advanced forms of window glass production (*i.e.* of wood-ash-lime glass), but also a more diverse, perhaps experimental, range of glass manufacture. Furthermore, the heterogeneous constellation of the different types of glass that show similarities with the early woodash types as defined by Wedepohl in connection with their appearance at sites that show very limited activity post-1050 leads to the conclusion that they must form part of the primary activities of the localities in question. Accordingly, the use-frame of the analysed windowpanes should most likely be placed between the beginning of the 9<sup>th</sup> and the end of the 11<sup>th</sup> centuries. As the sites that have been characterised as aristocratic also are strongly characterised by the politico-ritual use of conspicuous architecture and at times very large and imposing aristocratic buildings, we suggest the actual use of glassed windows in these buildings – for magical as well as for status-marking reasons. In conclusion, the presence of recognisable (visually and chemically) fragments of windowpanes leads us to suggest that the use of glassed windows should not be regarded as introduced as part of the early medieval (*i.e.* post-1100) construction of Christian churches, but very likely is a feature already known as part of the magnificent halls and temples of the Viking Age.

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## Notes

- 1 Four finds of window glass were made in the early excavations at Kaupang in Norway (Hougen 1969, 121) and 19 fragments have been recovered during the most recent excavations, five of which came from undisturbed Viking Age layers (Gaut 2011, 225). Unfortunately these were not available for the present study, but will form part of future analysis by the current group of authors.
- 2 The Framlev plank was examined a few years ago, both visually and with a CT scan. The annual growth rings were unfortunately very disturbed, with narrow growth rings and 'wild growth' (wavy growth rings), which means that the plank cannot be dated using dendrochronology (Niels Bonde, dendrochronologist, personal communication).

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## **Supplementary**

Supplements see .docx-attachment