Lost transparency!

Weathering phenomena on the archaeological window glass collection of the Cistercian Abbey of the Dunes - Koksijde (Belgium)

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ABSTRACT

As far as Belgium and archaeological window glass is concerned, the most important site is the Dunes Abbey, a former Cistercian abbey near the Flemish coastline. The collection contains approximately 15,000 fragments dating from the 13th to the 16th century. This glass was exposed to atmospheric weathering while *in situ* for several hundred years, buried for up to 400 years, excavated by different individual excavators in different eras and for over half a century stored in uncontrolled conditions. Moreover, different conservation treatments have been applied to the glass. Due to this, the collection was in a friable condition and we assume half of it has already been completely lost. The remaining collection retains fragments whose condition ranges between almost perfectly preserved material to being completely weathered to the point that no original glass survives. In this research, an important asset is recognizing what has already been lost and maximizing what is still available.

During recent conservation and stock making campaigns, the different weathering phenomena were separated into 9 groups based on empirical criteria and detailed registration. As a first step to further investigation of the weathering processes, quantitative SEM-EDX analyses are used to give better insight into the chemical composition of these groups. The aim is to bridge the gap between interpretative archaeologically and archaeological science and to develop a common terminology to evaluate the complexity of weathering phenomena in archaeological window glass collections which can be used as a tool for the assembling and interpretation of these collections.

Keyword list : window glass, stained glass, Dunes Abbey, archaeology, mediaeval, Cistercian, weathering, SEM-EDX

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1. INTRODUCTION

In this introduction, problems associated with the history of the site and their relation to the archaeological interpretation are taken into account. Different excavations carried out from the end of the 19th century until 2006 have revealed about 15,000 mediaeval and post-mediaeval window glass pieces. Although the total amount of window glass fragments appears enormous they are limited for such an extensive site. Nonetheless questions of taxonomy and social identity can be raised and the amount of material is sufficient to reconstruct the fenestration history the abbey. Preferably, material culture should be analyzed in contextual, diachronical and technological ways, in order to make an attempt to write the biography of these window glass fragments. This implies not only the life span of an artifact (the panes were blown, were part of a creation of a glazier, used in a building as fenestration, broken, mended, broken again, buried, excavated and stored for decennia) but also the way people think about it (who ordered it, paid for it, used it etc.).[1] For the final interpretation of the collection, we therefore try to integrate all these aspects as much as possible. The methodology consists of a comparative analysis based on a combination of detailed comparison of several material-technical properties of the glass fragments such as thickness, colour, traces of production and processing, decoration, contextual data and weathering. The high degree of fragmentation and the heterogeneity of the collection necessitates this kind of detailed archaeological analysis on the level of the fragment itself.

Processes of window glass decay obscure glass to a degree it might not even be identified as such and might be misinterpreted as for example stone, slate or ceramics. And yet apart from being severely deteriorated and fragmented these window glass fragments hold a wealth of information within their shape, technology and decoration. The deviation of phenomena is broad, ranging from almost perfectly preserved pieces, comprising none or limited phenomena, such as scratches, dulling and iridescence to extensive alteration characterized by thick altered top-layers and complete disintegration of the material where no original glass survives, as in the case of sugaring. Although the decay of archaeological glass is a well studied topic, the high degree of weathering typical for northern European mediaeval and post-mediaeval archaeological collections, is both an important problem for the study of archaeological window glass collections as well as a significant source of information to re-assemble certain pieces.

During recent conservation and stock-making campaigns, the different weathering phenomena were separated into 9 groups based on empirical criteria and detailed study. As a first step to further investigation of the weathering processes, quantitative SEM-EDX analyses are used to give better insight into the chemical composition of these groups. The aim is to bridge the gap between interpretative archaeologically and archaeological science and to develop a common terminology to evaluate the complex weathering phenomena in archaeological window glass collections. As Jones states, our task within this process remains to shift between the results as determined by material science techniques and what these might tell us in terms of the intentional and meaningful aspects of material culture.[2] So it can be used as a tool for the evaluation of the re-assembling of archaeological collections and might be useful to draw inter and intra site conclusions.

1.1 Our Lady of the Dunes – A short history

In 1107 the French hermit Ligurius settled in the dunes, northwest of the current village of Koksijde. Soon joined by kindred spirits, they organized themselves into a cloister community according to the rule of Saint-Benedict. From 1128 onwards a first wooden barn, a gift from the Count of Flanders, was used as a place for worship amidst the dunes. In 1138 the abbey joined the Cistercian order and started its leading role in the development of coastal Flanders.[3] The following decades acquisitions, gifts and exchanges of land lead to the establishment of a significant estate. Around 1300 the abbey is at the height of its power with 120 monks, 248 lay brothers and an international estate of up to 10,000 ha. The construction of a new abbey, which was said to be the biggest brick construction at that time in Flanders, started in 1214.[4] Some hundred fifty years later the construction works were more or less finished consisting of group of

Fig. 1: detail 'Flandria Illustrata', Antonius Sanderus, 1644 , collection of Museum Ten Duinen 1138 – Koksijde - Belgium

buildings, among which were a 110-120m long Gothic church and an important library with precious manuscripts.[5] As the Flandria Illustrata (Fig. 1), a copy of the Pourbus[6] Painting of 1580 indicates, the glass surface on the site must have been enormous. From 1400 onwards a gradual decline started caused by unfavourable political circumstances, large debts and a decrease of vocations. Besides this it was very hard controlling environmental factors such as an increasing mobility of parabolic dunes and rising groundwater. Planting slowed down the progression of the dunes at first but soon a large mobile dune became uncontrollable. From the end of the 15th century onwards the relocation of the abbey was discussed. Furthermore the position of the abbey was weakened by the iconoclastic revolt of 1566 and the subsequent 'Wars of Religion' between Protestants and Catholics (1568 –1648). In 1578 the abbey was abandoned after confiscation by the local protestant authority. The monks fled taking many of their treasures with them and the abbey was demolished shortly afterwards. After thirty years at the Ten Bogaerde abbey farm, which was rearranged as a temporary abbey during this period, the monks finally founded a new abbey in Bruges in 1627, partially constructed by recuperation of materials from the Abbey of the Dunes. The dunes finally covered the ruins of the abbey completely in the 17th century.[7]

1.2 A century of excavation campaigns[8]

In order to reconstruct past human activity, it is crucial to understand the context of the finds. These consist of the immediate matrix, its provenience and association with other finds.[9] Unfortunately for the Dunes most contextual information is lost. In order to reproduce as much fragmented knowledge as possible, it is important to examine the history of the excavations itself. This final process of interpretation will be done by post-excavation specialists, unaware of the details of the excavations by different individual excavators, except from numerous excavation diaries which are difficult to bring into relation to the material finds as present today.

In 1894, the canonical beatification of Idesbald van der Gracht, the third abbot of the abbey, was a first stimulus to the archaeological and historical investigation of the site. Systematic excavations started from 1949 onwards. The main goal was recovery of bricks in order to restore the Seminary in Bruges. Further excavations aimed at the uncovering of the abbey church, a specific research topic of that era. From 1952 to the end of the 1970s archaeologists, students and volunteers excavated on the site. From the 1980s onwards the archaeological investigation was conducted by the National Service for Excavations. Gradually, the archaeological and historical research brought new insights about the exceptional historical and archaeological value of the site and in 1986 the ruins became protected cultural heritage. Between 1999 and mid 2006 more archaeological research was carried out on different locations. Nowadays, the Abbey Museum Ten Duinen 1138 mainly encourages the accessibility of the collection for research goals and the public. Primarily the study of different material groups is encouraged. Rather than simply studying the different materials in isolation, their final goal is to create interpretative connections between all aspects of material culture of the Dunes.

1.3 The turbulent history of the archaeological collection

All excavation campaigns assembled a huge amount of archaeological window glass. The current collection contains approximately 15,000 fragments dating from the 13th to the 16th century. Two thirds of the collection is naturally coloured white glass and around 5,000 pieces are stained. Most of the stained fragments were once part of grisaille windows, but coloured (blue and yellow pot coloured, red flashed glass) and figurative glass is also part of the collection. This material was exposed to atmospheric weathering while *in situ* for several hundred years, subsequently it was destroyed in war by looting, dismantled by the monks or degraded by neglect and buried for hundreds of years in wet or damp environment. Afterwards it was excavated and stored in uncontrolled conditions. Moreover, different conservation treatments have been applied on this glass collection by well-intentioned amateur-conservators without professional training. During these campaigns conservators have tried to present material to the public in different ways, consolidating it to save it for future generations and regain its transparency by reheating the glass pieces. These well-intentioned

Fig. 2: Material as found in plastic bags in 2007 showing lots of pieces of window and vessel glass. After the loss of the weathering layers only a very thin and sometimes perforated bulk is left, including the loss of all techno-morphological and typo-chronological information.

campaigns have led to irreparable loss and irreversible interventions. Due to all this the collection is in a friable condition. The remaining collection retains fragments whose condition ranges between perfectly preserved glass to being completely blackened and sugared to the point that no original glass survives. Various fragments have lost their weathered layers partly or completely, leaving only the bulk as witness of the original material. (Fig. 2)

1.4 Research aim

During the current conservation campaigns and the study of the first contexts all weathering phenomena were separated into 9 groups based on empiric characteristics. Generally the goal is to substantiate the relevance of these groupings by quantitative SEM-EDX analyses to get better insight into the chemical composition of the altered layers of the different groups and by backscattered electron images of the different phenomena. This will be a first step to further detailed investigation of weathering processes of the window glass collections under study. After conservation treatment, the Dunes collection will be documented completely, examining the different phenomena based on the results of this research. The aim is to establish relationships between the different contexts based on all material-technical and morphological characteristics.

2. MATERIALS AND METHODS

2.1 Selection and preparation of the material

26 glass fragments from the different groups were selected for analysis. They were chosen diachronically and have been dated between the 13^{th} and the 16^{th} century based on material-technical properties and techno-morphological characteristics. The main criterion for the selection was the absence or presence of the different weathering phenomena and the dating of the material. Most of the samples are naturally coloured white glass, except two red flashed pieces. The state of the material varies from a good state of conservation (4 samples) to completely weathered material. By means of destructive sampling, small glass pieces (~5 mm) were cut from the glass to enable the research of the glass body itself as well as the different weathering products. The glass fragments (~5 mm per side) were embedded into acrylic resin and cut in order to expose a cross-section. The resin blocks were mechanically ground with silicon carbide paper and polished with diamond paste up to 1 µm in order to obtain a smooth surface. Finally the resin blocks were coated with a thin carbon layer and Scanning Electron Microscope Energy-Dispersive X-ray spectroscopy (SEM-EDX) measurements were performed. Documentation of the different phenomena is made using a light microscope Olympus SZX12 and with normal photography.

2.2 SEM-EDX measurements

Scanning Electron Microscope – Energy Dispersive X-ray spectroscopy (SEM-EDX) measurements were performed with a JEOL 6300 scanning electron microscope equipped with an energy dispersive X-ray detector. With this instrument, secondary electron and backscattered electron images (BEI) of the embedded samples were registered. The spectra were collected for 200 seconds by using a 2 nA electron beam current, an accelerating voltage of 20 kV and a microscope magnification of 500. These parameters were found to be suitable for quantitative analysis of glass without significant diffusion of sodium during the irradiation. The net intensities were calculated with the program AXIL (Analysis of X-rays by Iterative Least squares) and quantified by means of a standard less ZAF program.[10] Since this program takes the glassy matrix into account only the quantification of bulk glass is correct while quantification of weathered areas is only a good indication for the real concentration. When points of interest were located on a backscattered electron image and the area was not homogeneous at a magnification of 500 a real point measurement was performed, meaning that prevention of sodium diffusion is not guaranteed.

3 CLASSIFICATION OF ALTERATION PHENOMENA

3.1 Introduction

Alteration of glass can be caused by mechanical, biological, chemical and physical processes. The term weathering is described as the breakdown of the original glass by external influence, changing the composition of the material. It therefore covers a wide range of phenomena. Because glass deteriorates from the outside inwards[11], the loss of weathered layers removes the original surface. This results in the loss of surface including paint layers and engravings, manufacturing and processing traces and information about the original shape of the glass piece. Many factors affect the

current state of glass. First of all the composition of the glass and secondly its environment. Composition can be seen as important because of the differences between "durable" soda-lime-silica glasses and the corrosion sensitive mediaeval and post-mediaeval potash-lime and High Lime Low Alkali (HLLA) material.[12] Factors such as temperature, time, pH of the environment, surface area of the glass, micro-organisms, traffic vibrations, post-excavation treatment and earlier conservation treatments also have to be taken into account.[13] [14]Yet, figuring out most of these parameters is impossible.
Initially the evaluation in different groups was based on empirical characteristics using an understandable terminology for the dialogue between the archaeologist/material-specialist and the responsible conservator. The terminology was based on the visual features in combination with terms described in literature. The phenomena were described as: (1) scratches, (2) mat surface, (3) pitting, (4) iridescence, (5) crusts, subdivided in beige, brown/black and enamel like white-grey-blue crusts, (6) white/beige crusts at the grozing edges, (7) brown/black circular spots or Fe/Mn-browning, (8) sugared material (with decay to the core or with surviving bulk), (9) weathering phenomena at the height of the lead cames, giving an indication about the width of the lead wings (which will not be discussed in this paper) in the database.

3.2 Chemical composition of the analysed samples and its relation with the state of alteration

This study brought up the evidence of the two expected material groups, based on their chemical composition, namely potash-lime glass and HLLA material.[15] The distribution of the compositions according to age conforms to our predictions: the older group consisting of forest or potash-lime glass can be dated in the 13^{th} and 14^{th} century. The 16^{th} century material is HLLA-glass. The two groups have an overlap in the 15^{th} century. (Table 1) Up to now, no relation between the alteration phenomenon and the glass composition could be established. The main goal of this first attempt was to gain a better insight into the different phenomena and the relevance of the groupings.

3.3 Discussion of the different weathering phenomena

3.3.1 Good preserved fragments

3 different samples (cat. nr. 3529, 3404 and 2196) with no or very little weathering phenomena were selected to compare the main composition of this material with the more weathered pieces. The selected samples show some mechanical damage but this has had no effect on the transparency of the material.

3.3.2 *In situ* weathering phenomena

(1) **Mechanical damage** can have many causes and glass breakage is basically the most important cause which results in these small archaeological window glass pieces. Often scratches appear during window fabrication or installation. Also maintenance of the window itself and of inner and outer walls may cause damage as glaziers and other tradesmen can make scratches by resting their tools against the glass. Despite the damage, the property of the glass remains unchanged. Notwithstanding the initial harmless character of these scratches, they might subsequently induce other weathering phenomena.

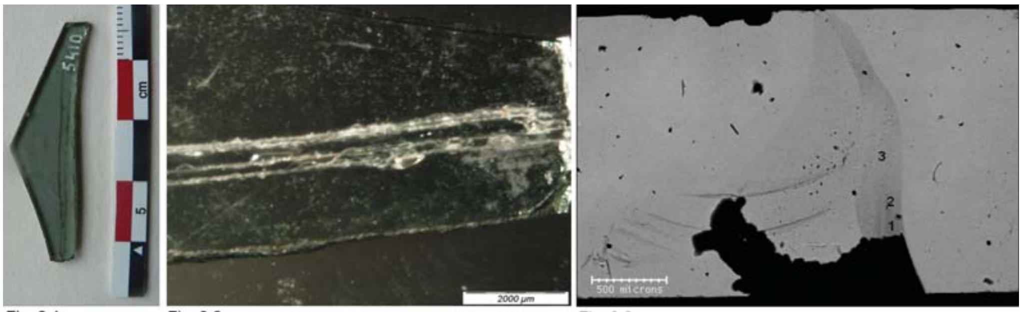


Fig. 3.1 Fig. 3.2 Fig. 3.3

Fig. 3.1 shows the scratched glass fragment cat. nr. 5410. Fig. 3.2. is a detail taken with an optical microscope. Fig. 3.3 is a BEI of a cross section of an embedded glass sample showing traces of diamond cutting. The numbers indicate points where X-ray point measurements were performed (Table 2)

The16th century sample above (Fig. 3.1) shows a cutting mistake of the glazier. Apart from the scratches the glass is perfectly preserved, without any dulling or iridescence. The different traces of diamond cutting - one next to the other – are easily noticed. (Fig. 3.2) When observed in a BEI of the cross section (Fig. 3.3) the depth of the mechanical damage is clearly visible (lack of original material) and an area of lower density is observed underneath the cut. Close to the cut (Table 2/1) an enrichment of calcium and a reduced relative silica content is noticed. The micro-cracks are probably due to the stress imparted to the glassy material by the act of cutting. Underneath the scratch on the right side, glass leaching seems to be facilitated by the damage created by the scratch itself.

(2) **Dulling** is the simplest type of weathering in which the glass loses its original clarity.[16] The material is still transparent but just a little mat. This kind of weathering occurs *in situ* and during burial.

(3) **Pitting** is a phenomenon in which indentations are visible in the glass surface, often with a white fill. (Fig. 4.1) There is a big variety in the sizes of the pits, described in literature as micro pitting, small pits and large pits. The pits, joining together, can produce an altered top-layer, which makes the glass quite opaque, thus losing its transparency.[17] Observing pitting phenomena in a backscattered electron image (Fig 4.2, 4.3, 4.4), it is clear that, next to the loss of material, the area underneath the pit itself is also consequently poorer in K and Ca, consisting of hydrated silica. (Table 3)

Fig. 4.1

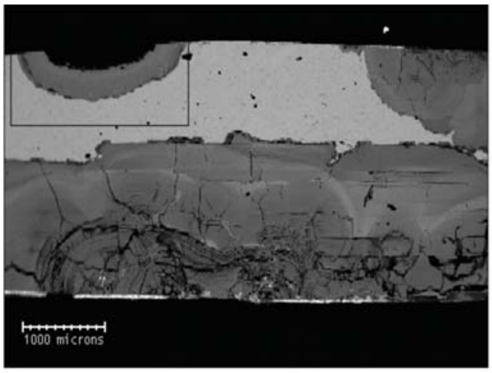


Fig. 4.2

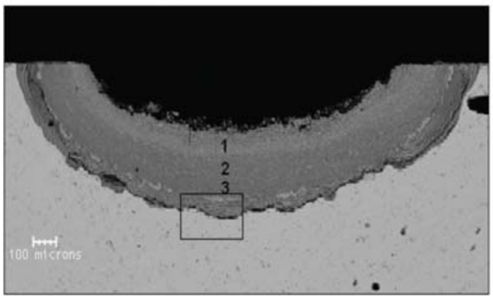


Fig. 4.3

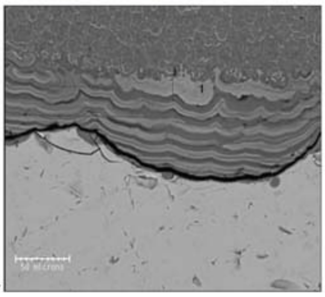


Fig. 4.4

Fig. 4.1 is a picture of glass fragment, cat. nr. 3089, showing pitting, taken with an optical microscope. Fig. 4.2 is a BEI of a cross section of the embedded glass sample showing clear evidence of pitting. The black rectangle indicates an area of which a more detailed BEI was taken (Fig. 4.3). The numbers indicate points where X-ray point measurements were performed (Table /1, 2, 3) and the black rectangle indicates an area of which a more detailed BEI was taken (Fig. 4.4). The number indicates the point where an X-ray point measurement was performed (Table 3/detail 1).

(4) **White-beige alteration on the grozed edges** of the glass pieces is caused where the glass was retained in the lead cames. This phenomena might have a relation to the putty used to make the window wind- and watertight, or may be due to the micro-climate occurring in the lead wings, or the reaction between the edges of the glass piece and the lead itself. (Fig. 5.1)

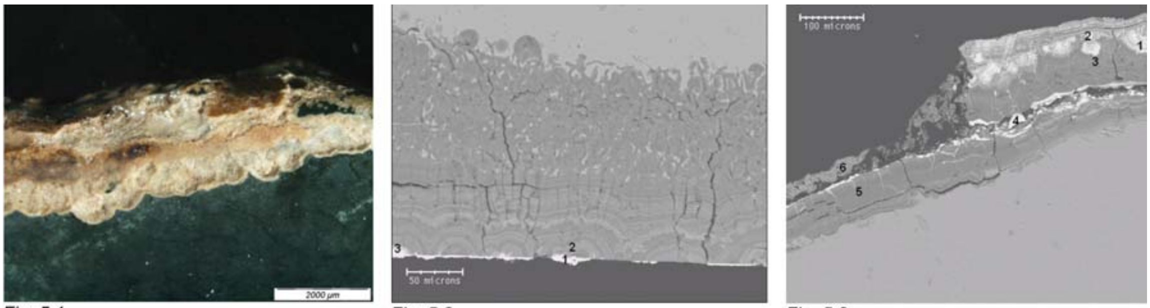


Fig. 5.1 Fig. 5.2 Fig. 5.3

Fig. 5.1 is a detail of glass fragment nr. 813 with white-beige alteration on the grozed etches (cat. nr. 813), taken with an optical microscope. Fig. 5.2 is a BEI of a cross section of an embedded glass sample of fragment nr. 813. The numbers indicate points where X-ray point measurements were performed (Table 4). Fig. 5.3 is a BEI of a cross section of an embedded sample from glass fragment nr. 936, that shows lead intrusion in the leached layer. The numbers indicate points where X-ray point measurements were performed (Table 5).

Two fragments were analysed to get insight in the origin of the weathering phenomena. The left fragment (nr. 813) shows a high content of Pb in point measurement 1 and 3. (Fig. 5.2 / table 4) The first sample might still raise some doubt about whether the Pb-particle is on top of the surface or as an inclusion in the weathered layer. For point 3 the Pb-inclusion is certainly part of the glass. The measurements of the second sample (nr. 936 – Fig. 5.3) confirm the results of the first sample with high lead concentrations in measurement point 1, 2 and 4 which are certainly part of the weathered layer. (Fig. 5.3 / table 5) Further research on this point needs certainly to be done.

3.2.2 Phenomena due to burial conditions

(5) **Iridescence** is a rainbow-like colouration of the glass surface caused by the scattering of light due to the lamellar structure of the altered glass, sometimes occurring alone and sometimes in association with other types of weathering. It is first visible in filmy patches and in a more advanced state it flakes off.[18] It is not uncommon on stained glass windows *in situ* but as it frequently occurs on recovered archaeological material it is put in this category.

(6) The **altered top-layer** is the solid-like outermost layer of weathered glass over a large part or the entire surface. These layers appear as a beige, brown/black coloured or white-blue-grey enamel-like material and they make the glass lose its transparency. It may be soft and powdery or hard and flinty. After ingress into the surface it might flake away leaving irregular bulk[19]. Losing this material goes hand in hand with the loss of technical, morphological and typo-chronological information. Underneath these layers the weathered material might be lamellar or have a sugared-like appearance.

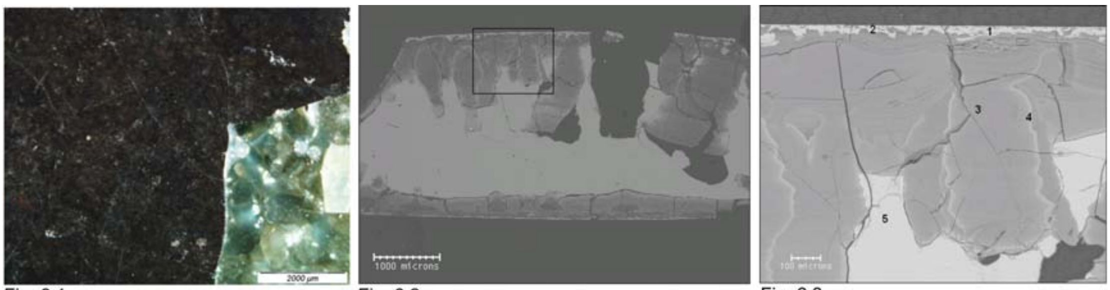


Fig. 6.1 Fig. 6.2 Fig. 6.3

Fig. 6.1 is cat. nr. 3316 a glass fragment with completely blackened surface, taken with an optical microscope. On the right side the altered top-layer broke off and the remaining bulk glass is visible. Fig. 6.2 is a BEI of a cross section of an embedded glass sample from fragment nr. 3316, showing the formation of an altered top layer. The black rectangle indicates an area of

which a more detailed BEI was taken (Fig. 6.3). The numbers indicate the points where X-ray point measurements were performed (Table 6).

The small 16th century sample has two hard and shiny, completely black top layers.(Fig. 6.1) The back-scattered image (Fig. 6.2, 6.3) shows a leached layer, with a very low content of Ca and K and on top of it an altered-top layer containing a very high amount of Mn, namely 30.8 wt% and 24 wt%. Looking at the complete black surface this is probably a type of manganese browning.[20 21]

(7)- **Brown-black bodies** appear as round or oval yellow-brown or brown-black spots. By growing and joining together they might cover the complete glass surface. Especially in the 13th and 14th century material of the collection of the Dunes, these bodies fall out easily leaving perforated thin layers of bulk.
This kind of black-brown staining was identified in a twofold way by Geilmann[22]: either by following present corrosion morphologies e.g. pits producing staining of concentric ring and star-shape or completely blackened corrosion layers[23] The other kind is a separate stain feature within layers of laminar corrosion such as circular deposits on the surface which are present only underneath the uppermost layer of the corrosion[24] or as dendrites growing vertically into layers of laminar corrosion.[25] The staining varies greatly in extent and morphology from localized described as spots or stars and resembling so-called Liesegang systems, to entirely blackened pieces[26]; or dendrites and feathering according to their morphology. A similar situation is found in Mn-staining, where the presence of MnO_2 in these bodies causes the surface of the glass to turn brown/black. [27,28]
The backscattered images of all the selected and studied samples show a high Ca-content. No high Mn-amounts are found in brown/black bodies. Thus in this case the cause of the colour has to be found in another type of material originating from the glass itself or intruding from the environment. It could be due to a change in oxidation state of the Fe but for this further investigation is necessary. It is clear that Mn-staining is only one possible manifestation of the brown black bodies.

8) **Sugared material** has an appearance comparable to sugar. Often underneath the altered top-layer it is a far-reaching alteration of the silica network, this doesn't prevent a thin layer of bulk being left in the middle.

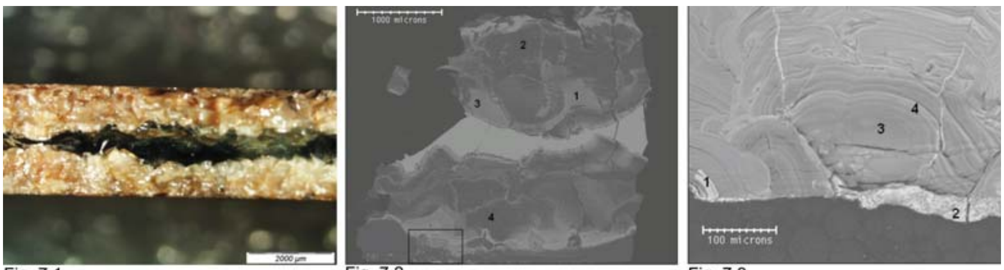


Fig. 7.1 Fig. 7.2 Fig. 7.3

Fig. 7.1 is a cross section of a sugared glass fragment, nr. 2947, taken with an optical microscope. Unaltered bulk glass remains in the middle of the fragment. Fig. 7.2 is a BEI of a cross section of an embedded sample from glass fragment nr. 2947 in which sugared layers are visible. The numbers indicate points where X-ray measurements were performed (Table /1-4).and the black rectangle indicates an area of which a more detailed BEI was taken (Fig. 7.3). The numbers indicate points where X-ray point measurements were performed (Table 7/detail 1-4).

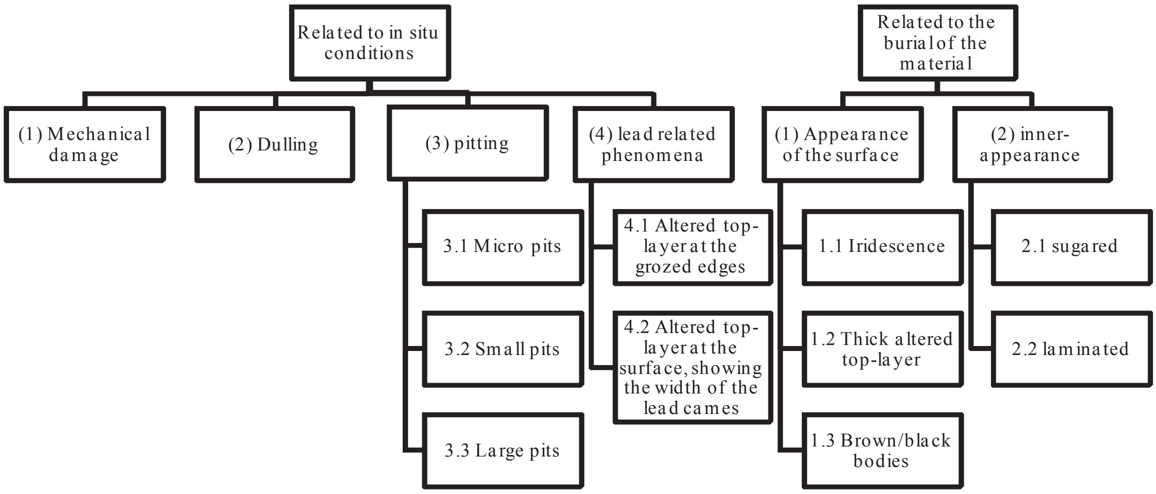
This 16th c piece (Fig. 7.1), is almost completely sugared with a small piece of bulk in the centre. On top of the leached layer, containing a lot of Fe is a crust with a high Ca-amount and hardly any Si. Fig. 7.3, point 1 (table 7 / detail 1) shows 46 wt% of Manganese. This single inclusion of MnO_2 is not visible with the naked eye.

5. CONCLUSIONS AND FUTURE RESEARCH

The analysis performed on the material of the Dunes provides important information on regrouping the weathering phenomena on the glass and providing a better insight into the origin, structure and chemical composition of the weathered layers. No relation between the alteration phenomena and the glass composition could be established. The main goal of this first attempt, was to obtain a better insight into the different phenomena and the relevance of the groupings. To evaluate these phenomena the history of the collection had also to be considered: on the one hand mechanical damage due to manufacturing, processing and use; and on the other weathering phenomena formed while the glass was *in situ* and due to the burial of the material.

This research has made a fine-tuning of the terminology and definitions possible. The terminology has now changed to a certain degree. The solid outermost layer will not be mentioned as crust anymore but will be referred to as an altered top-layer. The term “crust” will only be used as efflorescence of salts at the surface. The terminology gives no indication anymore about the chemical composition of the altered layers as up till now an empirical evolution in relation to the chemical aspects is not certain.

The flow chart as presented below will now be used for the evaluation of archaeological window glass collections. The relation between the thickness of the glass, the decoration layers and the different weathering phenomena will be used as a tool to re-assemble the collection and make inter-site relations.



In the past archaeological window glass collections have been largely ignored and much remains to be done to exploit their full potential. Over the next three years the collection of the Dunes will be evaluated completely. This will enable an overall evaluation and interpretation of the weathering phenomena of the glass and the paint layers to be conducted in relation to their techno-chronological and typo-morphological characteristics. It will enable more of the design to be established and reconstructions to be produced. This approach requires expertise and investment to quantify, asses and extract the information held in these window glass fragments. It also provides improved access to the collections. Managing archaeological window glass such as the Dunes-collection is an expensive and long term project. Finally, more in-depth studies are needed on the weathering phenomena of mediaeval and post-mediaeval window glass collections in Flanders to gain a better understanding of the different phenomena in relation to their geographical, chronological and typo-morphological characteristics.

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TABLE 1/ Bulk concentrations wt% presented as oxides of all the measured glass samples with a standard deviation of three different measurements using the 1 σ criterium (measuring conditions described in 2.2)

		type	date	production method	colour	tinge	type	thickness (min mm)	thickness (max mm)	av (mm)	MgO	Al2O3	SiO2	P2O5	SO3	ClO0	K2O	CaO	MnO	Fe2O3	BaO
good state	3529,0	HLLA	16,0	cylinder	white	dark green	pot coloured	2,49	3,31	2,9	5,3 ± 0,1	2,6 ± 0,1	57,7 ± 0,1	2,1 ± 0,1	0,3 ± 0,0	0,2 ± 0,0	4,3 ± 0,1	22,8 ± 0,1	0,8 ± 0,0	0,9 ± 0,0	0,5 ± 0,0
	3403,0	HLLA	16,0	cylinder	white	grey	pot coloured	1,86	2,07	1,965	4,0 ± 0,0	3,2 ± 0,1	62,1 ± 0,2	1,3 ± 0,1	0,1 ± 0,0	0,3 ± 0,0	7,0 ± 0,1	18 ± 0,1	0,9 ± 0,0	0,6 ± 0,0	0,4 ± 0,0
	2196,0	HLLA	15,0	cylinder	white	light green	pot coloured	2,34	2,61	2,475	3,6 ± 0,2	2,4 ± 0,1	61,6 ± 0,2	1,9 ± 0,0	0,0 ± 0,0	0,6 ± 0,0	4,9 ± 0,1	20,8 ± 0,2	0,8 ± 0,0	0,5 ± 0,0	0,3 ± 0,0
iridisation	3737,0	HLLA	16,0	cylinder	white	grey	pot coloured	1,32	1,42	1,37	4,2 ± 0,1	2,8 ± 0,1	60,8 ± 0,2	1,3 ± 0,0	0,2 ± 0,0	0,2 ± 0,0	6,9 ± 0,1	20,5 ± 0,1	1,0 ± 0,0	0,7 ± 0,0	0,4 ± 0,0
	5210,0	HLLA	16,0	cylinder	red		flashed	1,71	1,98	1,845	4,2 ± 0,1	2,8 ± 0,1	57,8 ± 0,1	2,1 ± 0,0	0,3 ± 0,0	0,4 ± 0,0	4,5 ± 0,0	23,0 ± 0,1	0,8 ± 0,0	0,8 ± 0,0	0,4 ± 0,0
	3797,0	HLLA	16,0	cylinder	white	grey	pot coloured	2,04	2,09	2,065	3,0 ± 0,2	2,5 ± 0,0	60,5 ± 0,2	2,0 ± 0,1	0,1 ± 0,0	0,5 ± 0,0	4,8 ± 0,0	22,8 ± 0,1	0,5 ± 0,0	0,6 ± 0,0	0,3 ± 0,0
mat	1949,0	potash-lime	14,0	crown	white	yellow green	pot coloured	2,96	3,39	3,175	4,8 ± 0,2	2,9 ± 0,0	49,5 ± 0,2	2,1 ± 0,0	0,1 ± 0,0	0,0 ± 0,0	10,0 ± 0,0	28,1 ± 0,0	1,0 ± 0,0	0,6 ± 0,0	0,7 ± 0,0
	2123,0	potash-lime	14/15	cylinder	white	olive	pot coloured	2,75	2,88	2,815	4,4 ± 0,1	2,5 ± 0,1	49,9 ± 0,1	1,6 ± 0,1	0,2 ± 0,0	0,0 ± 0,0	16,3 ± 0,0	22,4 ± 0,2	0,9 ± 0,0	0,6 ± 0,0	0,6 ± 0,0
	4286,0	potash-lime	14,0	crown	white	olive	pot coloured	2,62	3,08	2,85	4,8 ± 0,1	2,7 ± 0,1	52,1 ± 0,3	2,0 ± 0,1	0,1 ± 0,0	0,2 ± 0,0	15,5 ± 0,1	20,3 ± 0,2	0,9 ± 0,0	0,5 ± 0,0	0,5 ± 0,0
pitting	967,0	potash-lime	13,0	crown	white	green	pot coloured	3,81	4,65	4,23	5,2 ± 0,0	1,5 ± 0,1	56,4 ± 0,3	3,4 ± 0,1	0,1 ± 0,0	0,3 ± 0,0	13,8 ± 0,1	17,0 ± 0,1	0,7 ± 0,0	0,7 ± 0,0	0,4 ± 0,0
	3809,0	HLLA	15/16	cylinder	white	?	pot coloured	2,5	2,65	2,575	3,9 ± 0,1	0,8 ± 0,0	54,3 ± 0,2	3,5 ± 0,0	0,1 ± 0,0	0,4 ± 0,0	11,6 ± 0,1	23,4 ± 0,1	0,5 ± 0,0	0,5 ± 0,0	0,1 ± 0,0
	4893,0	int. HLLA/potash lime	16,0	cylinder	white	light green	pot coloured	1,9	1,93	1,915	5,2 ± 0,2	1,8 ± 0,0	58,0 ± 0,2	2,5 ± 0,0	0,1 ± 0,0	0,5 ± 0,0	8,6 ± 0,0	18,9 ± 0,1	0,9 ± 0,0	0,7 ± 0,0	0,3 ± 0,0
manganese	2221,0	HLLA	16,0	cylinder	white	yellow	pot coloured	1,85	1,88	1,865	3,7 ± 0,1	3,1 ± 0,0	59,9 ± 0,2	1,8 ± 0,1	0,2 ± 0,0	0,5 ± 0,0	5,3 ± 0,0	21,2 ± 0,1	0,8 ± 0,0	0,6 ± 0,0	0,3 ± 0,0
	2147,0	potash-lime	14/15	cylinder	white	green	pot coloured	2,41	3,09	2,75	5,1 ± 0,1	1,4 ± 0,0	56,3 ± 0,1	3,3 ± 0,0	0,1 ± 0,0	0,3 ± 0,0	14,1 ± 0,1	17,1 ± 0,1	0,7 ± 0,0	0,8 ± 0,0	0,4 ± 0,0
	4615,0	HLLA	16,0	cylinder	white	light green	pot coloured	2,06	2,27	2,165	3,7 ± 0,1	3,5 ± 0,1	59,6 ± 0,2	1,3 ± 0,0	0,1 ± 0,1	0,1 ± 0,0	8,0 ± 0,1	21,0 ± 0,1	1,1 ± 0,0	0,9 ± 0,0	0,5 ± 0,0
sugared	903	potash-lime	13	?	white	green	pot coloured	5,33	5,71	5,52	5,0 ± 0,2	1,6 ± 0,0	55,4 ± 0,1	3,3 ± 0,1	0,0 ± 0,0	0,3 ± 0,0	13,8 ± 0,1	18,1 ± 0,2	0,7 ± 0,0	0,8 ± 0,0	0,3 ± 0,0
	2947	potash-lime	15/16	?	?	?	?	2,57	2,7	2,635	6,4 ± 0,1	1,2 ± 0,1	52,5 ± 0,2	3,7 ± 0,0	0,1 ± 0,0	0,3 ± 0,0	16,2 ± 0,1	15,3 ± 0,2	1,2 ± 0,0	0,7 ± 0,0	0,2 ± 0,0
	2611	potash-lime	13/14	cylinder	?	?	?	3,68	4,19	3,935	4,4 ± 0,1	1,2 ± 0,1	48,3 ± 0,1	1,0 ± 0,0	0,3 ± 0,0	0,0 ± 0,0	19,3 ± 0,1	23,0 ± 0,1	1,1 ± 0,0	0,4 ± 0,0	0,7 ± 0,0
crust(black)	3316	HLLA	16	?	white	?	?	2,11	2,5	2,305	3,6 ± 0,1	2,3 ± 0,0	60,0 ± 0,2	1,9 ± 0,0	0,3 ± 0,0	0,2 ± 0,0	6,4 ± 0,1	21,8 ± 0,1	0,4 ± 0,0	1,2 ± 0,0	0,2 ± 0,0
crust(beige)	1961	altered	13	?	?	?	?	4,36	6,05	5,205	0,2 ± 0,1	4,4 ± 0,4	90,4 ± 0,4	0,1 ± 0,0	0,3 ± 0,0	0,1 ± 0,0	0,6 ± 0,0	2,9 ± 0,1	0,1 ± 0,0	0,8 ± **0,1**	0,3 ± 0,1
crust(blue)	2711	altered	16	?	?	?	?	2,65	2,73	2,69	0,1 ± 0,0	2,2 ± 0,1	93,3 ± 0,1	0,1 ± 0,0	0,4 ± 0,0	0,2 ± 0,0	0,4 ± 0,0	2,0 ± 0,0	0,0 ± 0,0	0,8 ± 0,0	0,3 ± 0,0
pale crust	813	potash-lime	14/15	cylinder	white	light green	pot coloured	2,74	3,15	2,945	4,2 ± 0,2	2,2 ± 0,1	56,5 ± 0,2	2,8 ± 0,1	0,1 ± 0,0	0,3 ± 0,0	13,1 ± 0,1	18,0 ± 0,0	0,6 ± 0,0	1,2 ± 0,0	0,3 ± 0,0
	2087	potash-lime	14/15	?	white	green	pot coloured	3,05	3,42	3,235	5,0 ± 0,1	1,6 ± 0,1	55,4 ± 0,1	3,3 ± 0,0	0,1 ± 0,0	0,3 ± 0,0	13,7 ± 0,0	18,2 ± 0,1	0,7 ± 0,0	0,8 ± 0,0	0,3 ± 0,0
	936	potash-lime	14	cylinder	white	green	pot coloured	3,49	4,05	3,77	4,8 ± 0,1	1,6 ± 0,1	55,5 ± 0,1	3,2 ± 0,0	0,1 ± 0,0	0,3 ± 0,0	13,7 ± 0,0	18,4 ± 0,1	0,7 ± 0,0	0,8 ± 0,0	0,4 ± 0,0
scratches	5503	HLLA	16	cylinder	white	yellow	pot coloured	1,25	1,53	1,39	4,9 ± 0,1	2,6 ± 0,0	57,7 ± 0,1	1,7 ± 0,1	0,3 ± 0,0	0,3 ± 0,0	5,0 ± 0,0	22,0 ± 0,1	0,9 ± 0,0	1,1 ± 0,1	0,6 ± 0,0
	3902	potash-lime	13	cylinder	white	light green	pot coloured	3,65	3,85	3,75	4,1 ± 0,1	1,4 ± 0,0	61,7 ± 0,3	2,4 ± 0,0	0,1 ± 0,0	0,4 ± 0,0	11,8 ± 0,1	16,2 ± 0,2	0,6 ± 0,0	0,7 ± 0,0	0,3 ± 0,0
	5410	HLLA	16	cylinder	white	grey	pot coloured	1,86	1,89	1,875	5,2 ± 0,1	2,5 ± 0,1	58,8 ± 0,5	1,8 ± 0,0	0,4 ± 0,0	0,4 ± 0,0	4,1 ± 0,0	21,3 ± 0,3	0,7 ± 0,0	1,0 ± 0,0	0,6 ± 0,0
rest(bulk)	2321	potash-lime	13/14	crown	white	green	pot coloured	3,96	4,52	4,24	6,8 ± 0,0	1,8 ± 0,0	48,5 ± 0,1	4,2 ± 0,0	0,1 ± 0,0	0,3 ± 0,0	16,5 ± 0,0	18,9 ± 0,0	1,0 ± 0,0	0,9 ± 0,0	0,3 ± 0,0
	2337	potash-lime	13/14	crown	white	light green	pot coloured	3,58	3,92	3,75	4,6 ± 0,1	2,7 ± 0,0	48,3 ± 0,1	1,6 ± 0,0	0,1 ± 0,0	0,0 ± 0,0	14,2 ± 0,0	26,0 ± 0,0	1,1 ± 0,0	0,6 ± 0,0	0,6 ± 0,0

5410	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	BaO
1*	1,4	1,6	1,9	22,6	0,5	0,1	0,3	6,4	50,2	4,9	8,2	1,9
2*	1,0	2,7	1,9	46,2	1,1	0,3	0,4	5,9	35,7	1,6	2,1	1,0
3*	1,9	4,0	2,2	54,2	1,5	0,4	0,4	4,9	27,6	0,9	1,2	0,6

Table 2: 5410 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

3089	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	BaO
1*	0,3	0,6	1,1	42,6	13,0	0,5	0,2	0,4	38,7	0,4	2,0	0,2
2*	0,5	0,2	1,2	54,2	8,4	0,2	0,1	0,7	32,5	1,1	0,9	0,2
3*	0,2	0,3	1,3	70,3	4,3	0,2	0,1	1,1	19,4	1,8	0,9	0,3
Det. 1*	0,6	2,2	1,0	61,1	4,2	0,1	0,2	6,5	22,5	0,7	0,8	0,1

Table 3: 3089 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

813	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	CuO	PbO
1*	0,0	0,5	1,3	6,2	16,5	4,0	1,6	0,2	23,7	0,3	2,5	0,5	42,6
2*	0,0	0,6	3,9	76,0	2,4	1,6	0,1	0,8	8,9	0,1	3,2	0,2	2,3
3*	0,0	0,2	2,8	36,4	9,3	5,7	1,3	0,6	15,3	0,2	2,3	0,1	25,9

Table 4: 813 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

936	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	CuO	PbO
1*	0,0	0,1	1,0	19,3	8,2	1,4	0,7	0,6	27,2	0,7	5,8	0,5	34,5
2*	0,3	0,7	2,7	65,7	4,7	1,0	0,7	0,8	9,0	0,2	2,7	0,3	11,3
3*	0,9	1,1	3,8	80,5	1,8	0,9	0,3	1,2	5,0	0,1	1,7	0,2	2,8
4*	0,4	0,9	1,8	40,2	10,7	3,1	1,2	0,5	16,1	0,3	3,7	0,2	20,9
5*	0,4	0,5	3,7	87,9	0,3	0,5	0,3	0,8	2,7	0,1	1,6	0,1	1,3
6*	0,0	0,0	0,1	1,6	1,7	51,3	0,0	0,1	44,1	0,1	0,2	0,2	0,6

Table 5: 936 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

3316	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	BaO
1*	0,6	0,6	4,2	46,5	1,0	1,0	0,5	0,7	9,2	30,8	4,0	1,0
2*	0,3	0,3	4,2	52,3	1,1	0,8	0,8	0,9	9,6	24,0	4,9	0,9
3*	0,5	0,3	5,6	82,8	0,5	0,1	0,1	0,8	5,6	0,0	3,2	0,5
4*	0,0	0,2	4,0	86,0	0,1	0,0	1,0	0,5	5,2	0,0	2,6	0,4
5*	1,7	3,6	2,3	59,9	1,8	0,4	0,2	6,4	22,0	0,4	1,1	0,3

Table 6: 3316 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

2947	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	ClO	K_2O	CaO	MnO	Fe_2O_3	BaO
1	0,4	0,2	2,2	88,7	2,0	0,0	0,0	0,3	4,4	0,2	1,4	0,2
2	0,2	0,1	3,3	82,6	3,5	0,0	0,1	0,5	6,3	0,4	2,7	0,4
3	0,2	0,1	2,0	90,3	1,4	0,0	0,1	0,4	4,1	0,2	1,0	0,2
4	0,7	0,1	3,0	79,9	4,8	0,2	0,1	0,4	8,1	0,5	2,0	0,2
Det. 1*	0,2	0,5	1,3	23,9	3,8	0,4	0,1	0,4	14,2	46,0	8,1	1,0
Det. 2*	0,0	0,7	0,9	8,0	29,4	0,1	0,1	0,4	21,8	0,2	38,2	0,3
Det. 3*	0,0	0,0	2,2	55,9	2,4	0,3	0,1	2,5	14,1	0,4	20,5	1,6
Det. 4*	0,4	0,5	5,2	85,0	1,0	0,2	0,1	1,0	3,8	0,0	2,6	0,2

Table 7: 2947 Point measurements taken at the indicated spots, the concentrations (wt %) are presented as oxides.

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