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The investigation and characterisation of colourless glass from
forensic and archaeological contexts using multiple
interdisciplinary analytical techniques

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**The investigation and characterisation of colourless glass
from forensic and archaeological contexts using multiple
interdisciplinary analytical techniques**

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Abstract

The techniques used to analyse glass in forensics and archaeology differ: forensic analysis relies almost completely on Refractive Index, whereas archaeology uses compositional analyses. This thesis focuses on examining, explaining and challenging those differences through the analysis of colourless glass from forensic and archaeological contexts.

Two major studies are undertaken, one focussing on stained and painted glass from Christ Church Cathedral, Oxford, and one based on modern automotive glass. The analytical techniques common to each discipline are applied to the samples of glass used in the research. The studies each focus on individual research questions; the Christ Church study investigates the 17th century Van Linge window scheme, the compositions of fragments of glass from throughout the cathedral's history are investigated, and shown to separate into distinct compositional groups. The study also successfully recreates the Van Linge window scheme; and the historical and compositional analyses allowed the study of one of the in-situ painted windows in the cathedral. The automotive glass study investigates the complex relationship between glass manufacturers and vehicle manufacturers. The research revealed that certain makes of vehicle were beginning to group and glass from specific areas of the world was also grouping together. This study highlights the potential use for glass as a tool for intelligence gathering rather than just as evidence.

The application of the different analytical techniques to each study is discussed along with the merits of using each of the techniques. The potential of using forensic techniques in archaeology and archaeological techniques in forensics is evaluated. Specifically, LA-ICP-MS, which is rarely used in forensics, could be an innovative and potentially important tool for the forensic evaluation of cars and other glass evidence. A discussion of the research and databases needed to make the most of the techniques is assessed.

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1 Introduction

1.1 Aims of the Thesis

This thesis focuses on the analysis of colourless glass from archaeological and forensic contexts using techniques available to both disciplines in order to determine the provenance of the glass. The three main aims of the thesis were to:

- Assess the use of analytical techniques in the analysis of glass.
- Determine which techniques are used in each discipline and why.
- Determine whether the techniques from one discipline can be applied to the other and the levels of success involved with this approach.

Two major studies were used to achieve the above aims, and each of these had further secondary aims:

Christ Church

- To recreate the Van Linge window scheme.
- To determine the compositions of the different periods of cathedral glass.
- To determine a method for identifying different periods of restoration work within the upstanding windows.

Automotive Glass

- To determine the complex relationships between glass and vehicle manufacturers.
- To determine the extent to which individual manufacturers can be identified through compositional analyses.

The provenancing of glass is an established concept in the field of archaeology. The techniques used for the analysis of glass are constantly being improved and updated, and applied to previously unstudied samples or archaeological settings. The samples are analysed to determine the major, minor and trace elements, and to determine the isotopic ratios of specific elements within the glass. In this way the nature of the raw materials can be characterised and the relationship between the raw materials in the final product can be assessed. This information can be used to aid the identification of the potential source of the raw materials and in some cases even potentially be used to identify the manufacturer of the glass.

The forensic analysis of glass determines whether samples found at a crime scene (control samples) match samples removed from a suspect (suspect samples). In most cases a limited number of techniques are used to achieve this depending on the level of discrimination required to accurately answer the question of ‘do the samples match?’ Although the number of techniques being developed for use in the field of forensic glass analysis is improving, a certain amount of time and resources are needed to ensure the technique is robust enough to stand up to the scrutiny of the courts. Once a technique is deemed robust enough, then it can become an established technique.

Both of the disciplines of archaeology and forensics are asking the same fundamental question, but from different perspectives, i.e. where does the sampled glass come from? Despite this similarity between the subjects the approaches taken towards answering this question are different. Not only are different techniques used, but when similar techniques are used the application of those techniques is different. This thesis seeks to investigate why this discrepancy between the disciplines exists and whether either discipline can learn from the other. Can a novel methodology be devised which utilises the skills of both disciplines to serve a common goal in the analysis of glass?

1.1.1 Thesis Overview

In order to address the aims of the thesis, two major studies were undertaken, one archaeological and one forensic, these studies utilised the analytical techniques used within each field. These studies represent original work in their own right and each leads to important archaeological and forensic interpretations. The shape of this thesis is outlined in Figure 1-1.

The first study looks at historical window glass from Christ Church Cathedral, Oxford, while the second looks at modern auto glass. The Christ Church glass chosen is predominantly colourless window glass from dateable periods of the cathedral’s history. This is compared to auto window glass which is also colourless and dateable, unlike modern architectural glass which although colourless, can be difficult to date accurately. Each study uses both forensic and archaeological techniques to analyse the glass samples. Once the samples have been characterised in each study, attempts are made to determine the origin of the glass, and conclusions are drawn based on the individual circumstances. A general discussion looks at the merits of the different techniques used

in the analysis of glass, in order to determine the usefulness of applying these to the alternate discipline. For example, do the forensic methods of glass analysis contribute to the archaeological interpretation of glass, and vice versa?

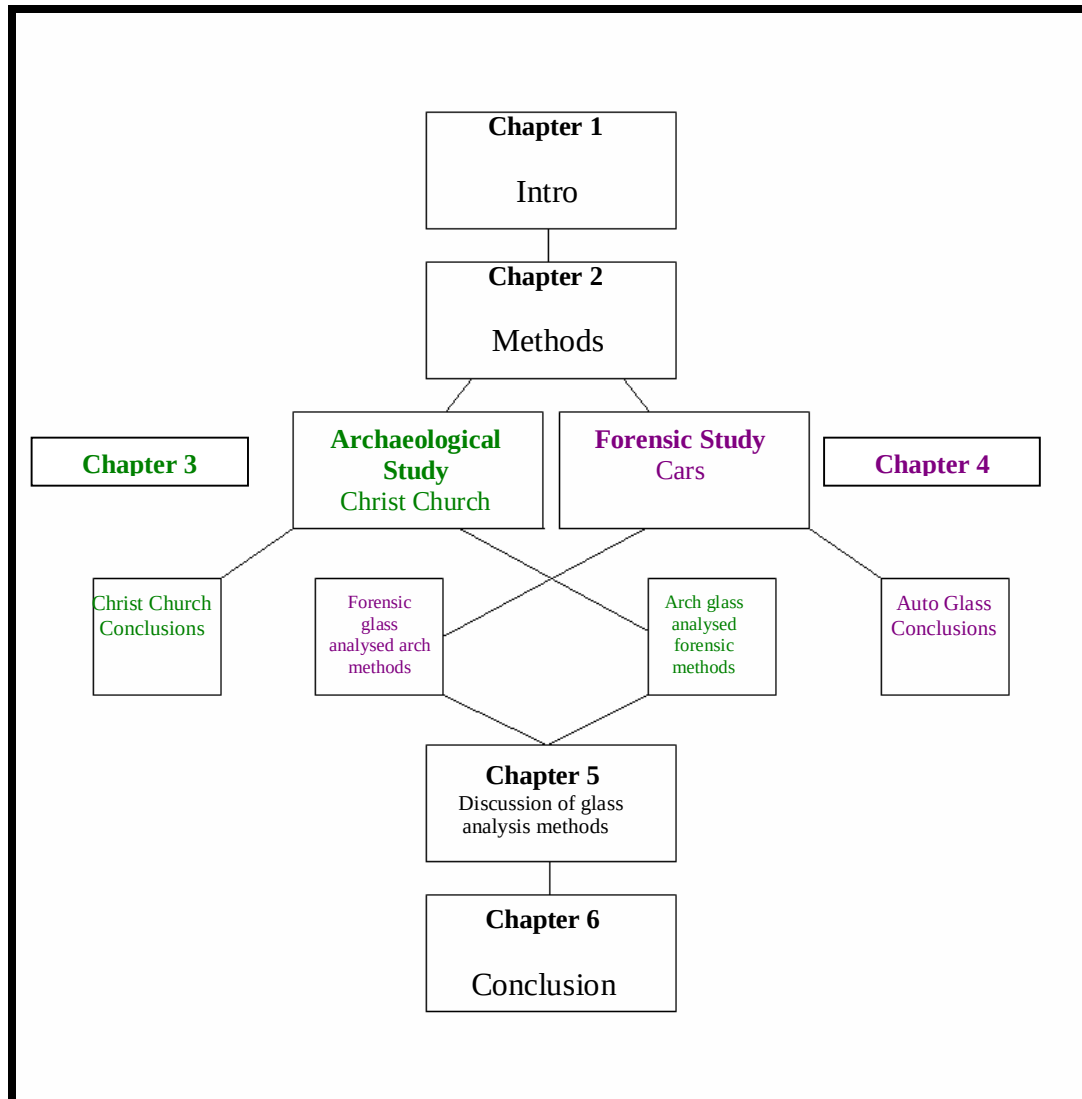


Figure 1-1 Structure of Thesis

1.1.1.1 Christ Church

Christ Church Cathedral was chosen as the historical study because in 2002, a large quantity of stained, painted and colourless glass fragments were discovered in a coal bunker in Tom Quad. These fragments were identified as being from windows that had been removed from the cathedral during the 1850s and 1870s renovations of the building. The style of the imagery on the different fragments has allowed some of them

to be attributed to specific art-historic periods, i.e. 17th century, Victorian or Medieval. The collection of glass at Christ Church contains over 9000 fragments; the cathedral also has examples of glass from the different periods still in the windows. This study used archaeological and forensic techniques to analyse the glass and determine whether the fragments could be more accurately ascribed to specific historic periods or artists based on the chemical composition of the samples. The results are then interrogated in an attempt to determine whether the origin of the samples can be identified. An attempt is made not only to identify the potential origin of the glass fragments, but also who painted them, when and where they may have been located in the cathedral. This leads to a discussion of what the cathedral may have looked like and, specifically focussing on the 17th century building, the emotions that may have been evoked by experiencing the atmosphere that would have been created; essentially, how the building functioned as a place of worship.

In terms of the Christ Church glass, each sample was analysed using Scanning Electron Microscopy – Wavelength Dispersive Spectrometry (SEM-WDS) (90 samples) to determine the major and minor elements, 24 samples were analysed using Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS) to investigate the trace elements and these latter samples were all taken from known, identified windows. Also, six samples of Christ Church glass along with two Egyptian glass samples and two Roman glass samples were analysed by Refractive Index (RI). The samples used in the RI analysis were specifically selected to reflect a range of dates of archaeological glass. This was in order to ascertain the extent to which this technique could be used in archaeological analysis and whether the technique could be used as a screening method within archaeology as it can be in forensics. After the elemental data had been interpreted, a Hand-Held X-ray Fluorescence (HH-XRF) technique was used to analyse some of the glass within one of the upstanding 17th century windows.

1.1.1.2 Automotive Glass

Modern car glass was chosen for the other major study for two reasons; firstly, a modern comparison of colourless window glass was required, and secondly, samples of auto glass were more easily datable than samples of architectural glass. Most car windows contain information as to the manufacturer of the window, the date it was

made and the location of the plant where it was made. Although this information is available on car windows, the samples of glass collected all came from scrap yards and so, where possible this information was recorded. One of the reasons the samples for this study were chosen from scrap yards, was due to the secrecy and commercial sensitivity that surrounds both the glass manufacturers and the forensic practitioners. Both parties are very polite and helpful in terms of the general information relating to glass analyses, but both are unwilling to release information relating to the composition and analyses of specific glasses. A total of 24 samples of auto glass were analysed using SEM-WDS to determine the major and minor elements, and with LA-ICP-MS for the trace elements. Of these samples 19 were sent for isotopic analysis and also RI analysis. The cost of the isotopic analysis meant that only a limited number of samples could be analysed. These 19 samples were chosen based primarily on the quantity of each brand of car i.e. five Fords (American), four VWs (German), two Citroëns (French), two Fiats (Italian) and two Rovers (British). Of the remaining four samples, three were side windows (two German and one Japanese) and one was a windscreen (Japanese). These samples also showed a range of car manufacturer and country, although the origin of the glass may not have been from these countries. The same samples were used in the RI analysis, this meant that all 19 samples had been subjected to all the analytical techniques, and an extra 5 had been analysed for the major, minor and trace elemental compositions.

1.1.1.3 Originality

Both of these studies are original; the windows and collection of fragments at Christ Church Cathedral have never previously been studied, and this research draws together not only current archaeological and forensic techniques used in the analysis of glass, but also examines the history and archaeology of the building itself. The Christ Church study combines cutting edge science with historical and archaeological investigative techniques to examine the nature of this public structure. The research shows how the turbulent history of the cathedral is reflected in the windows and the glass fragments housed in the collection. This aspect of the thesis demonstrates the benefits of using a multi-interdisciplinary approach to the study of glass. The auto glass study also compares the samples forensically and archaeologically, but examines the

extent to which there are similarities and variations between vehicle brands and between manufacturers. A survey of car windows across the Defence Academy demonstrates the variation in glass manufacture that can exist within a single vehicle, while also showing any patterns that occur in a specific make of car over time. The auto glass was chosen over modern architectural glass in order to have a degree of control over the samples i.e. information as to the manufacturer of and date of the glass. This research has also highlighted the complex relationship between the manufacture and economics of automotive window production. Conclusions are then drawn about the nature of the auto glass industry and what this means in terms of forensic glass investigations.

The thesis concludes by comparing the techniques used in both forensic and archaeological glass analysis to each other. The advantages and disadvantages of each technique are discussed in relation to the different disciplines. Suggestions are made as to how the techniques could be best used and incorporated into the alternate discipline, and how the approaches to the subject of glass analysis may need to be re-evaluated in order to utilise the different techniques to their fullest potential. In other words, can a mutually beneficial approach to glass analysis be developed?

1.2 What is Provenancing?

“The provenance determination of archaeological and historical artefacts relies on the assumption that there is a scientifically measurable property that will link an artefact to a particular source or production site” (Degryse et al. In Press).

The term provenance is relatively undefined, it is often used in the art world to describe the history of the artefact, or in production terms to imply the potential source of manufacture (Wilson & Pollard 2001). Therefore, the basic concept of ‘provenancing’ an item is to determine its source of origin. In terms of glass analysis this means determining where the raw materials used in the production of the glass may have come from and/or where the glass may have been manufactured. In theory the materials in the glass are matched to the correct geographical source location; this relies on being able to identify the correct signature of the raw material, and that these are inherent from the geological source from which they originated. It is also assumed that the geological signature is not transformed physically or chemically during the

manufacturing process (Ixer 2007). Also, each raw material is assumed to have an individual geological signature, for example, sand sourced from Scotland will have a different signature to sand sourced from Turkey (Degryse et al. In Press). In terms of glass analysis it is also worth noting that the manufacturing processes involved can also leave a signature in the finished product, further complicating the interpretation of the signatures involved, for example, glass can be contaminated by the crucible material (Jackson et al. 2003). In other words, because the chemical properties of the artefact (in this case glass) are characteristic of the raw material source of the object, the composition of the artefact is effectively a ‘chemical fingerprint’ (Wilson & Pollard 2001).

In order to provenance an item there are a number of assumptions which are made:

- The chemical signature/fingerprint of the raw materials varies between geological sources and that these signatures can be related to geographical locations. The inter-source variation needs to be greater than the intra-source variation for the source to be successfully identified.
- Some of the chemical characteristics of the raw materials are present in the final product either unchanged or changed in a predictable way.
- That any mixing of raw materials that occurs during the production of an artefact can be reasonably accounted for.
- That any post-depositional processes i.e. weathering that may affect the chemical signature can be accounted for, or suitable allowance can be made (Wilson & Pollard 2001).

First the composition of the different samples analysed must be compared and any differences between the samples determined, i.e. are distinct compositional groups forming (Inter-group variation)? Once the difference between the groups has been established it is then necessary to determine whether there is any similarity with existing groups of known provenance. Then the results can be compared to the data for specific raw materials to see if the artefact may have used raw materials from a specific source. This latter point presupposes knowledge of all the characteristics of all the possible sources of a particular raw material, which is rarely the case (Harding et al. 2004). Homogeneity between sources can make provenancing difficult; therefore, the technique will only ever confirm that an item did not come from a location. “*The definition of a provenance study must therefore first identify the attainable outcomes*” (Wilson & Pollard 2001: 510).

The idea that an artefact produced in a particular area will carry a 'geochemical fingerprint' is not new. The majority of provenance studies have had the goal of creating a chemical link between a group of objects and a geographically defined source of raw material (Wilson & Pollard 2001). This idea has formed the basis of many archaeological theories relating to the migration of peoples, as well as social interactions and exchanges (Pillay 2001). Despite this until the late 1990s the focus of glass analysis was directed towards the understanding of the fundamentals of early glass technology (Freestone 2005). Broad compositional categories, such as those by Sayre and Smith (1961) were established and in some cases a geographical or cultural origin for the glasses had been suggested (Wilson & Pollard 2001), but for the most part little further progress had been made. The composition of most ancient glass was known to be soda-lime-silica, and any analysis that did nothing more than re-affirm that fact did little to further the study of ancient glass (Smith 1971). More recently, a lot of work has been undertaken in attempting to provenance various glass artefacts and to determine whether certain glasses came from specific workshops or not (Freestone 2005). Studies of the methods and techniques used to produce various archaeological glasses, along with their chemical compositions, have been applied to a variety of (pre)historic glasses (Freestone 2005). But, these provenancing techniques and ideas have not been applied to modern glass.

The general compositions and manufacturing processes of modern glass are well known and researched, but, the glass still needs to be characterised for the purposes of forensic analysis. In forensic analysis the samples are matched with each other to determine a common source of origin, the techniques which provide the more robust data and therefore the best evidence for the courts are chosen for the analysis (Trejos & Almirall 2005). In terms of 'forensic provenancing' there is an attitude of 'if it works, why change it?' (Lovelock 2008 per. comm.), therefore, the challenge becomes not only determining whether different techniques are viable for glass analysis, but also, whether the attitudes towards the provenancing question can and need to be changed.

1.3 Techniques of Provenancing

In terms of the forensic analysis of glass fragments the only methods in common usage are Refractive Index (RI), Density and Scanning Electron Microscopy – Energy Dispersive Spectrometry (SEM-EDS) (Curran et al. 2000). Other methods have been and are being developed, for example, the use of laser related techniques such as Laser Induced Breakdown Spectroscopy (LIBS) to analyse the trace elements within the samples, but they are in the experimental stages and are not used routinely in the forensic analysis of glass (Curran et al. 2000). The first choice forensic technique currently used to determine whether samples of control and suspect glass match is RI. If the RIs of the samples are indistinguishable then the glass is usually determined to be from the same source (Sanger 1985). Some laboratories will use the density measurements of the glass in the same way. If further information is required, for example, the samples have statistically indistinguishable RIs but there is still some question over whether the samples are from the same source or not, then the forensic scientist will sometimes use elemental analysis (Harrison et al. 1985). Because the forensic glass analyst is often only asked to determine whether two or more samples have come from the same source or not, there is no need for them to employ further techniques or to interrogate the evidence further once this question has been answered.

Archaeological glass is provenanced using a number of techniques. The basic idea is to analyse the chemical composition of the glass samples in order to determine where the raw materials may have come from (Hartmann et al. 1997). In some cases, where there is a lot of evidence to suggest that the raw glass was manufactured on the site it was found, using the local raw materials available, it may be possible to test the hypothesis, and attempt to experimentally re-create the glass (Hatton et al. 2008). In most cases the situation is more complex. For example, the raw materials have been transported to the primary workshop where the raw glass is made, thereby, not necessarily giving the glass the signature of the manufacturing site directly. The raw glass could have been shipped to another location for working into a vessel and then further exported as a final product. In this sense the characterisation of the glass will have signatures of these processes, but the task of determining where the item was originally made or from where the raw material constituents came is challenging. The idea is that the signature of specific raw materials is unique and that by determining the

various signatures within the glass one should be able to determine which raw materials were used in a given product (Ixer 2002).

The techniques frequently used to analyse the composition of the glass include SEM-EDS and SEM-WDS both used to determine the major and minor elemental composition. LA-ICP-MS is used to determine the trace elemental composition of the glass, and Isotope analysis is used to determine the isotopic composition of the samples, usually Nd and Sr, but occasionally other isotopes such as Pb can also be used (Henderson et al. 2005). As with forensics other techniques are being experimented with and developed for example X-ray Fluorescence (XRF), but the most common methods are those mentioned above. This thesis used a combination of all of the above mentioned archaeological techniques along with the forensic technique of RI determination to analyse stained and painted glass from Christ Church Cathedral, Oxford, and a series of samples taken from car windows. The idea was to compare the techniques in terms of both forensic and archaeological samples and then to see if the techniques or methods of application from one discipline could be applied beneficially to the other.

1.4 Background

“Of all the ‘arts of fire’, only glass is defined by...thermal conditioning, being described scientifically as a ‘super-cooled liquid’. It has even been referred to as a ‘fourth state of matter’, because it has a liquid molecular structure which makes it transparent, though its viscosity is so high that it appears solid” (Turner 1999: 111).

1.4.1 What is Glass?

For many years the traditional definition of glass was ‘an inorganic product of fusion cooled to a rigid condition without crystallising’ (Paul 1990), this refers to what most people would consider to be glass, i.e. an amorphous solid. In recent times, organic glasses have been formed and not all glasses are formed by a fusion process (Varshneya 2006). Virtually any material can be used to make a glass, organic or inorganic, and there are a number of different processes which can be employed to form glasses, including cooling from a high temperature melt, the sol-gel process, and even

chemical vapour deposition processes (Shelby 2005). Therefore, neither the materials, nor the processes involved, can be accurately used to define a glass, so what is glass?

All glasses have two common characteristics; no glass has a long range, periodic atomic arrangement, and all glasses exhibit time-dependent glass transformation behaviour (Shelby 2005). This means that the structure of the glass is not crystalline, i.e. the particles are not arranged in a regular lattice formation. Also, the melt needs to be cooled over a specific time-period in order to optimise glass formation: the melt needs to be cooled quickly enough to suppress the nucleation or growth of any crystals present (Vogel 1985), but slowly enough as to impart the required physical properties to the glass.

Traditionally a glass is formed by cooling the melt below its freezing point (Paul 1990). If the melt is allowed to cool naturally below the melting temperature of the crystal, the liquid will often revert to its crystalline form. If cooled fast enough, the viscosity of the melt will increase and at a point below the freezing temperature the melt will become so viscous that the atoms cannot further re-arrange themselves and the melt continues to cool and solidify in the amorphous or glassy form. The structure of the liquid becomes fixed and therefore no longer temperature dependent (Shelby 2005).

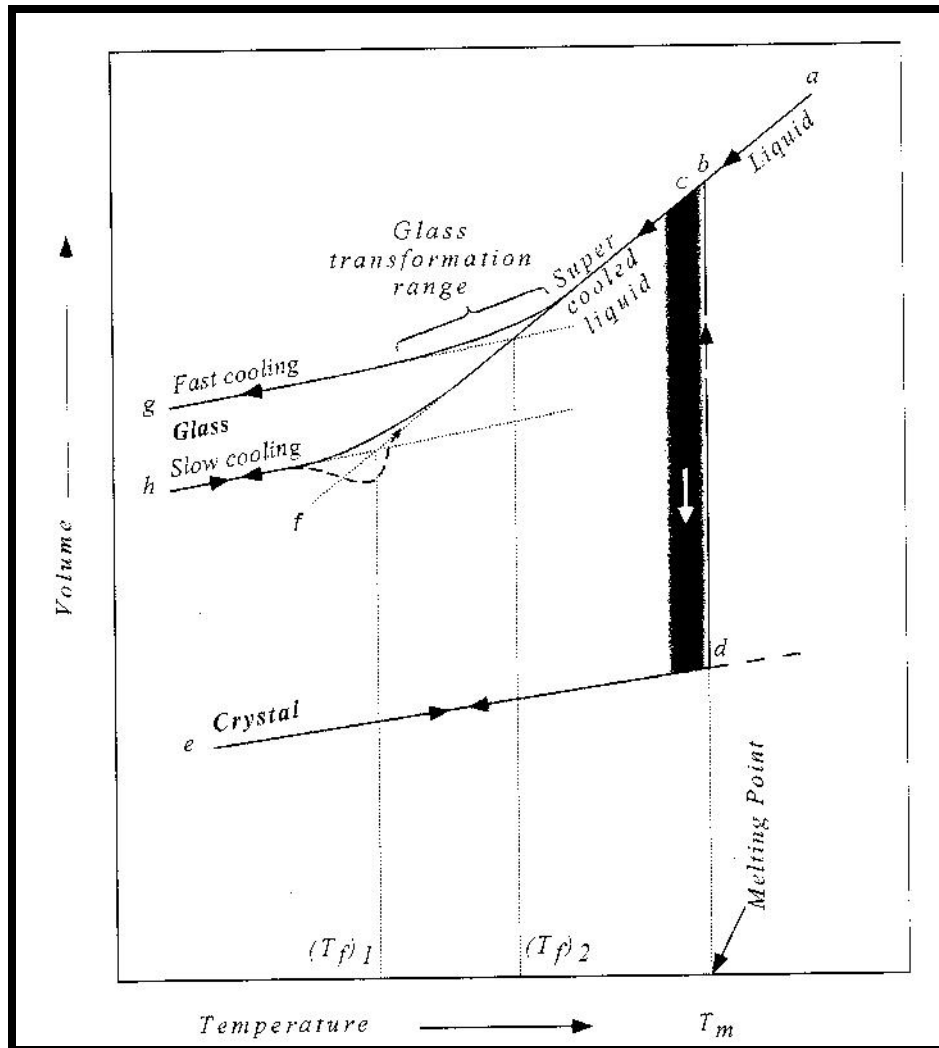


Figure 1-2 Relationship between glassy, liquid and solid states (Varshneya 2006: 19)

In Figure 1-2, the volume-temperature diagram represents what happens to the glass melt on cooling. On cooling the liquid from the initial state the volume decreases steadily, if the cooling rate is slow, and nuclei are present, then crystallisation will occur at the freezing temperature T_m . The volume will decrease sharply and the solid will continue to crystallise. If however, the cooling rate is more rapid, crystallisation does not occur at T_m and the volume of the liquid continues to decrease at a constant rate. At temperature T_f the slope changes and the liquid begins to solidify as the viscosity increases. T_f therefore, is the glass transition temperature and only below this is the material a glass. At T_f the viscosity is very high, c. 10^{13} poise (Paul 1990). Glasses are more easily formed if either the viscosity is very high at the melting temperature of the crystalline phase which would form from the melt, or if the viscosity increases very rapidly with decreasing temperature (Shelby 2005).

A glass is more likely to form if the crystallisation rate is small and the cooling rate is great (Turnbull 1969). Crystallisation or devitrification can occur with some glasses if the cooling rate is too slow or the glass is reheated (Hares 1984). If no crystal nuclei are present, then crystal growth cannot occur (Shelby 2005). There is a temperature limit above which crystals cannot exist, this is referred to as the liquidus temperature, and is dependent on the composition of the glass. Unfortunately, the crystals which form in glass are seldom of the same chemical composition as the glass. In some cases more than one crystalline phase may appear and the different phases may have different liquidus temperatures (Hares 1984). To create a true glass the size of the crystals needs to be reduced by melting and the further growth and nucleation needs to be inhibited by rapidly cooling the material (Vogel 1985).

There is no definitive hypothesis that adequately explains the formation of glass in all known systems (Paul 1990). The atoms in glasses form extended three dimensional networks, but these networks are not periodic and symmetrical (Zachariasen 1932). The glass is isotropic, i.e. the atomic structure is the same in all directions, and this is because of the lack of long range periodic atomic arrangement.

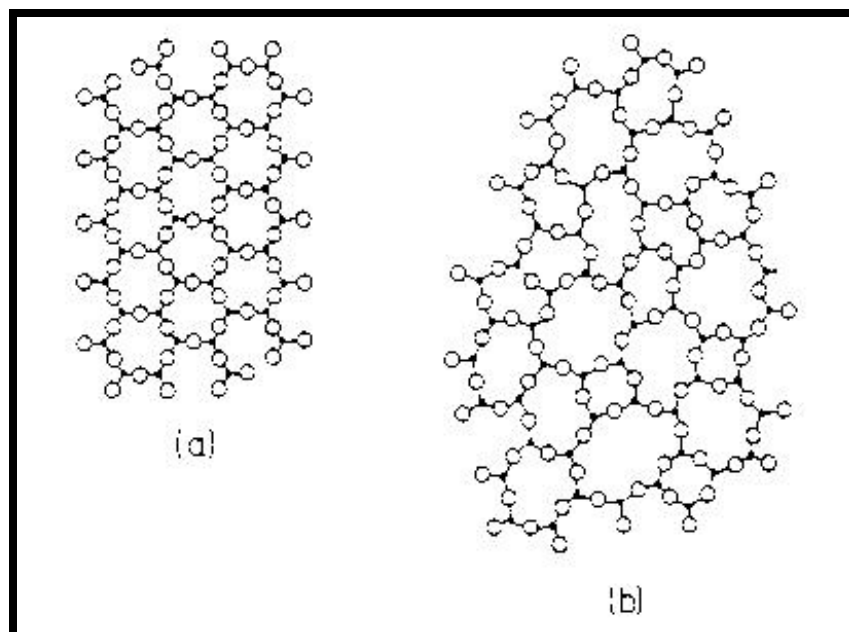


Figure 1-3 2D representation of the structure of a) a hypothetical crystalline compound and b) the glassy form of the same compound (Paul 1990: 11)

Figure 1-3 represents the crystalline and glassy structures of the same hypothetical compound. The image shows how the tetrahedra remain connected but the

structure is now amorphous. In order to form a glass “*sufficient network cations must be present to allow a continuous structure to form...the network is an open structure, and...that sufficient bonds linking the network polyhedra exist for the formation of a continuous network structure...[and] the melt must be cooled under the proper conditions*” (Shelby 2005: 9).

Glass must contain at least one component such as silica or boric oxide which is capable of forming the random structure (Hagy et al. 1984). This is known as the ‘network former’ and in the case of most archaeological or commercial glasses is silica. Other common network formers are B_2O_3 , GeO_2 and P_2O_5 (Paul 1990), these along with SiO_2 can all form glass on their own if the right conditions are met. As_2O_3 and Sb_2O_3 can produce a glass is cooled very rapidly; TeO_2 , SeO_2 , MoO_3 , WO_3 , Bi_2O_3 , Al_2O_3 , Ga_2O_3 and V_2O_5 will not form a glass on their own, but will form a glass if combined with a suitable amount of a second oxide (Paul 1990). All of the glasses researched in this thesis are silicate glasses; therefore, it is the formation of silicate glasses that will be discussed here. The network former in silicate glasses, as mentioned above, is silica (SiO_2) the silicon atom is bonded to oxygen atoms and these oxygen atoms can then link to further silicon atoms (bridging oxygens). In a pure silica glass all of the oxygen atoms are bridging (Hares 1984). Although pure silica glass has a wide range of applications, its use for standard ‘everyday’ items would be extremely expensive due to the high temperatures ($>2000^\circ C$) needed to produce vitreous silica (Shelby 2005). In antiquity, the furnace technology did not exist to create the high temperatures needed. In order to lower the melting temperature of the silica a fluxing agent needs to be added, such as Na_2O or K_2O . These ‘network modifiers’ will lower the melting temperature to $<1600^\circ C$ (Shelby 2005). The addition of these oxides disrupts the continuity of the network because some of the oxygen bonds ionically with the sodium (or potassium) now present. This oxygen is now only bonded to one silicon atom and is therefore a non-bridging oxygen (Hares 1984). The network modifier weakens the network by creating an end to the structure, i.e. by bonding with the oxygen and making it non-bridging it stops the further development of the network. The large cation will be accommodated in the cavities in the network (Vogel 1985). The most common fluxes are alkali oxides; other oxides such as PbO can also be used to help lower the melting temperature. Some oxides act as intermediates and can either be network formers or

network modifiers depending on the nature and amount of the other components in the melt (Hagy et al.1984), examples of intermediates would be magnesium or zinc (Hares 1984). Figure 1-4 shows diagrammatically the relationship between the atoms in a soda-lime-silica glass.

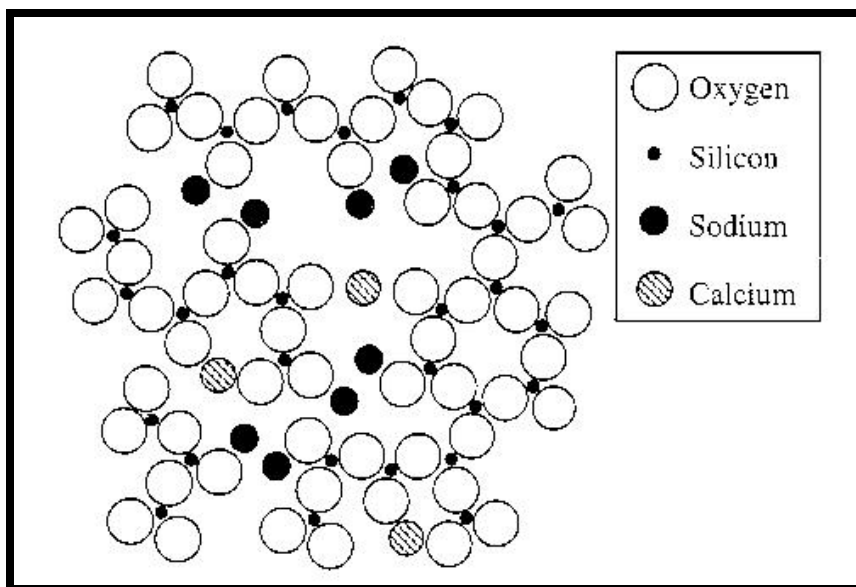


Figure 1-4 A 2D diagram of the structure of soda-lime-silica glass (Shelby 2005: 83)

A glass made just of SiO_2 and Na_2O would be unstable and susceptible to damage from water, therefore, a stabiliser like lime (CaO) or lead (PbO) is also needed (Hodges 1981). Soluble silicates are sometimes known as ‘waterglass’ and are used in adhesives, cleaners and protective coatings (Hares 1984). Stabilisers work by creating a bridge between two non-bridging oxygens and therefore allow the network to continue. Too little stabiliser and the glass has poor chemical durability, too much stabiliser and the glass is prone to devitrification. The lime is usually combined with a small amount of alumina or magnesia in order to prevent the occurrence of devitrification (Hares 1984).

In terms of modern commercial glasses, most will contain a small amount of other oxides which do not affect the physical properties of the glass but aid the manufacturing process, for example, small amounts of arsenic, antimony or some sulfates are added as ‘fining agents’ (Hares 1984). The idea of a fining agent is to reduce the amount of bubbles in the melt. Other oxides are added to specifically influence the physical properties of the glass for example, they may colour or decolour specific glasses, or oxides such as B_2O_3 can be added to aid the heat resistant properties

(Paul 1990). In these cases the oxides are deliberately chosen and added, in antiquity some of these oxides may have been present in the glass but this is more likely to have been because of an impurity in the raw material used than because it was deliberately added.

“Virtually any material can be formed as a glass under the proper experimental conditions. Kinetic theories describing nucleation and crystal growth rates allow the prediction of these conditions...These general trends correlate quite well with earlier theories of glass formation, which were based on structural and bonding considerations” (Shelby 2005: 25).

1.4.2 History of Glass Manufacture and Usage

“A ship belonging to traders in soda once called here, so the story goes, and they spread out along the shore to make a meal. There were no stones to support their cooking-pots, so they placed lumps of soda from their ship under them. When these became hot and fused with the sand on the beach, streams of an unknown translucent liquid flowed, and this was the origin of glass” (Pliny 1991).

1.4.2.1 Early Glass

Pliny the Elder is writing in the 1st century AD is describing man-made glass, but the first glasses used were natural, for example, obsidian has been used since prehistoric times in the manufacture of tools and artefacts. This natural substance was durable and sharp and could be relatively easily shaped. Obsidian is formed from the quickly chilled lava of a volcanic eruption; it is black in colour and occurs in many places around the world (Vose 1980). Other natural volcanic glasses also exist; these vary in colour and composition from obsidian and are usually found at lava boundaries (Vose 1980).

The earliest man-made glasses are Bronze Age beads, seals, inlays and plaques from Mesopotamia, with core-formed vessels appearing later around the close of the 16th century BC (Grose 1991). The knowledge of glass manufacture then quickly spread to northern Syria, Cyprus, Egypt and the Aegean. During the late Bronze Age glass was

a rare commodity, it was formed from crushed quartz pebbles, plant ash and colourants (Shortland 2007). The raw glass could then be transported in the form of ingots.

It is assumed that the ancient glassmakers followed a simple model, similar to the modern day ethos, of using a small number of relatively pure raw materials (silica, flux, lime, colourant), and that these were heated in a single stage at high temperatures to produce glass (Shortland 2007). As mentioned before, the silica component was likely to have been quartzite pebbles, and the flux would have been halophytic plant ash, the lime component would either have entered with the plant ash or possibly added deliberately as a separate component (Shortland & Eremin 2006). Despite this simple model, early glasses are chemically complex with at least 12 elements (oxygen, sodium, magnesium, aluminium, silicon, phosphorous, sulphur, chlorine, potassium, calcium, titanium, and iron) being routinely present in concentrations above c. 0.05 wt% in colourless glass (Rehren 2008).

1.4.2.2 Roman

By the Roman period, glass manufacturing had spread to Europe, and both the raw materials and the techniques used to manufacture the glass had further developed. For example, the technique of glass blowing revolutionised the production of glass. The Romans also appreciated the plastic properties of softened glass, and it was this combined with the blowpipe which led to an explosion in the manufacture of glass (Stern 1999).

The other striking development in terms of Roman glass manufacture was the control over the colour of the glass. Colourisers and de-colourisers were used in conjunction with furnace control to provide a wide variety of hues, and the popularity of colourless glass increased during this period (Jackson 2005). As glass production spread throughout the Roman world, glassmakers began setting up factories in the western provinces (Vose 1980). The glass of this period was still of a soda-lime-silica composition, but the form which the soda took changed. No longer were halophytic plant ashes being used, instead glass makers were utilising mineral soda or natron. The purer sodium salts contained less potassium and magnesium content (Freestone 2005).

During the 4th-5th centuries AD the Roman Empire splits, the East ruled from Constantinople continues much as it always had, while the West ruled from Rome

begins to crumble. To imply that the glass ‘industry’ remained stable and unchanged during this period would be misleading, there are considerable changes occurring especially during the later 4th century AD. For example, we see the emergence of HIMT glass, so-called for its High Iron, Manganese and Titanium contents (Arletti et al. 2008), but also, the quality of the glass itself begins to decrease becoming much more ‘bubbly’ in appearance (Foster & Jackson 2009). We also see a decrease in the number of glass forms which is reduced down to only common tableware (Aerts et al. 1999). An increase in the levels of certain trace elements in the glass such as zinc or zirconium has also been noted for the later 4th-5th centuries (Aerts et al. 1999). The detection of these higher levels of trace elements has often sparked the debate over whether new sources of raw materials are being exploited (the ‘localised’ glass production model), or whether this is the signature of earlier Roman glass being recycled in the form of cullet.

1.4.2.3 Medieval

By the Middle Ages the use of wood-ash as a flux had spread throughout most of Europe (Eramo 2006). Because of the use of wood-ash as a flux, the glasses of medieval Europe were rich in potassium oxide, but were also largely confined to this area (Freestone 2006). Potash glasses also tended to have higher lime contents and therefore also required a higher melting temperature than soda-lime glasses (Eramo 2006). Forest glass was manufactured in Europe until the 16th century AD (Dungworth 2008 pers.comm.); the most prevalent area in the England for glass production was the forest region around the NW of Sussex and the SW of Surrey (Winbolt 1933). Since several kinds of sand and alkali could be used to manufacture common glass, the industry was never tied to a particular locality. The small furnaces used for melting and working the glass could be quickly and easily built with little capital needed. Therefore, in medieval times the industry tended to be migratory, often following either the demand of the market or the need for fuel (Godfrey 1975).

Forest glass was normally green in colour, the intensity of this varied depending on the purity of the silica source and the thickness of the finished product. In the early medieval period both window glass and vessel glass were probably made in the same furnace, but as the demand for stained glass windows increased during the high medieval period the production of glass for this purpose became more specialised

(Godfrey 1975). During the medieval period window glass could be decorated with a range of colours, this was known as pot metal glass (Hodges 1981), but some colours were too opaque in the windows, and this led to the development of flashed glass, where a thin layer of coloured glass was fused onto a colourless glass, and allowed the colour to be transparent (Hodges 1981).

A study looking at the distribution of different glass types across medieval France identified two distinct types, sodic containing greater than 6 wt% Na_2O , and calco-potassic containing greater than 22 wt% $\text{CaO}+\text{K}_2\text{O}$ combined (Barrera & Velde 1989). Barrera and Velde felt that the distribution of these glasses across France could reflect either commercial exchange or a gradual shift in production methods. A similar story was recorded for medieval glass from Germany. The use of beech wood ash replaced mineral soda as a flux at around 900AD, and wood ash glass continued in use until another change during the late medieval period (Hartmann 1994). While the amount of CaO in the glass either stayed the same or increased, the amount of K_2O decreased, from 20% in the medieval glass to around 4% in the late medieval glass (Hartmann 1994). Hartmann suggests that these changes could reflect the restrictions being placed on the amount for wood used for the production of glass across Europe. This later glass is High Lime Low Alkali (HLLA) glass, and this became the dominant glass of the 17th century (see section 3.12.1).

1.4.2.4 17th Century

In Elizabethan Britain (1558-1603), although the government felt the glass industry was a promising enterprise worthy of encouragement, it was also a source of anxiety (Polak 1968). Britain relied on her timber-built Navy, and the glass industry was destroying valuable woodlands (Polak 1968). In 1615 an edict prohibited the use of wood in the glass industry, thereby preserving the forests and forcing glass manufacturers to develop other methods of manufacture, such as the use of coal (Polak 1968). During the 17th century there is an increase in both domestic and imported window glass (Willmott 2002); three types of window glass were prevalent during this period, broad glass, crown glass and cylinder glass.

Broad glass was widely used in the middle ages, in this technique the glass blower shaped a gather of glass and then by swinging the blowing iron generated

enough centrifugal force to extend the sphere into a cylinder with closed ends (Martlew 2008). A pontil was then attached to the other end of the glass, opposite the blowpipe and when the blowing iron was cracked off, a hole was left at the end of the cylinder of glass. This end of the glass was reheated in the Glory Hole and the end was opened out to the same size as the rest of the cylinder. The cylinder would then be split along the length and placed in a kiln with a flat floor and allowed to sag until mostly flat (Godfrey 1975).

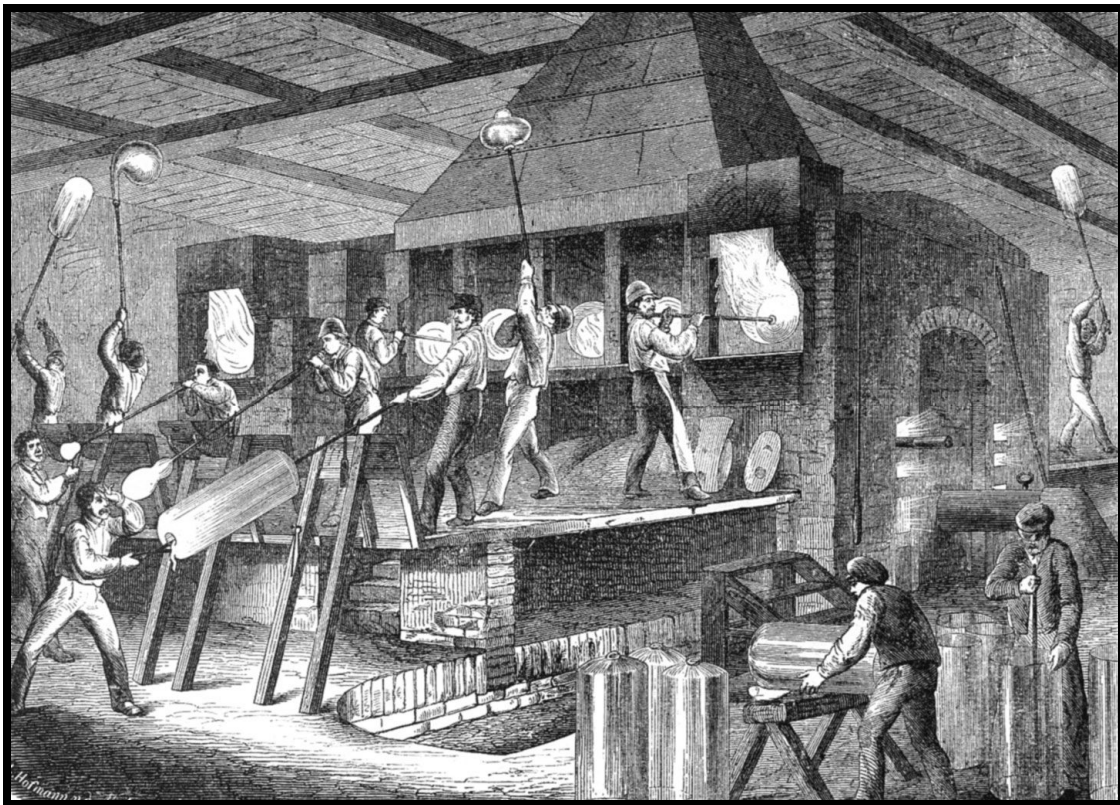


Figure 1-5 Broad Glass Manufacture c.1865 (www.britannica.com 2010)

As the date of this engraving (Figure 1-5) shows this method of manufacturing flat glass was in use for quite some time. The use of this technique throughout the ages has been shown in numerous drawings and engravings, for example Diderot in his *Encyclopédie* of 1765 also depicts the technique (Martlew 2008). The second method of flat glass production popular from the middle ages onwards was that of Crown Glass. In this method, a bubble of glass is blown and then attached to a pontil (Godfrey 1975), the pontil is then spun and again, the centrifugal forces open and flatten the bubble of glass, this time creating a large disk or table. The glass solidifies relatively quickly and has a fire-polished finish, although the glass itself is not perfectly flat (Martlew 2008). When

the glass is broken from the rod, a characteristic ‘bull’s eye’ is left at the centre (Godfrey 1975). Various sizes of table could be created and these were then cut into panes, with the central bull’s eye being left over at the end (Martlew 2008 pers. comm.). Nowadays the bull’s eye is seen as a fashionable feature in glass and can often be seen used for decorative purposes, but, in the medieval and subsequent periods, this was the cheapest part of the glass (Martlew 2008 pers. comm.). The process of Crown Glass manufacture is shown in Figure 1-6.

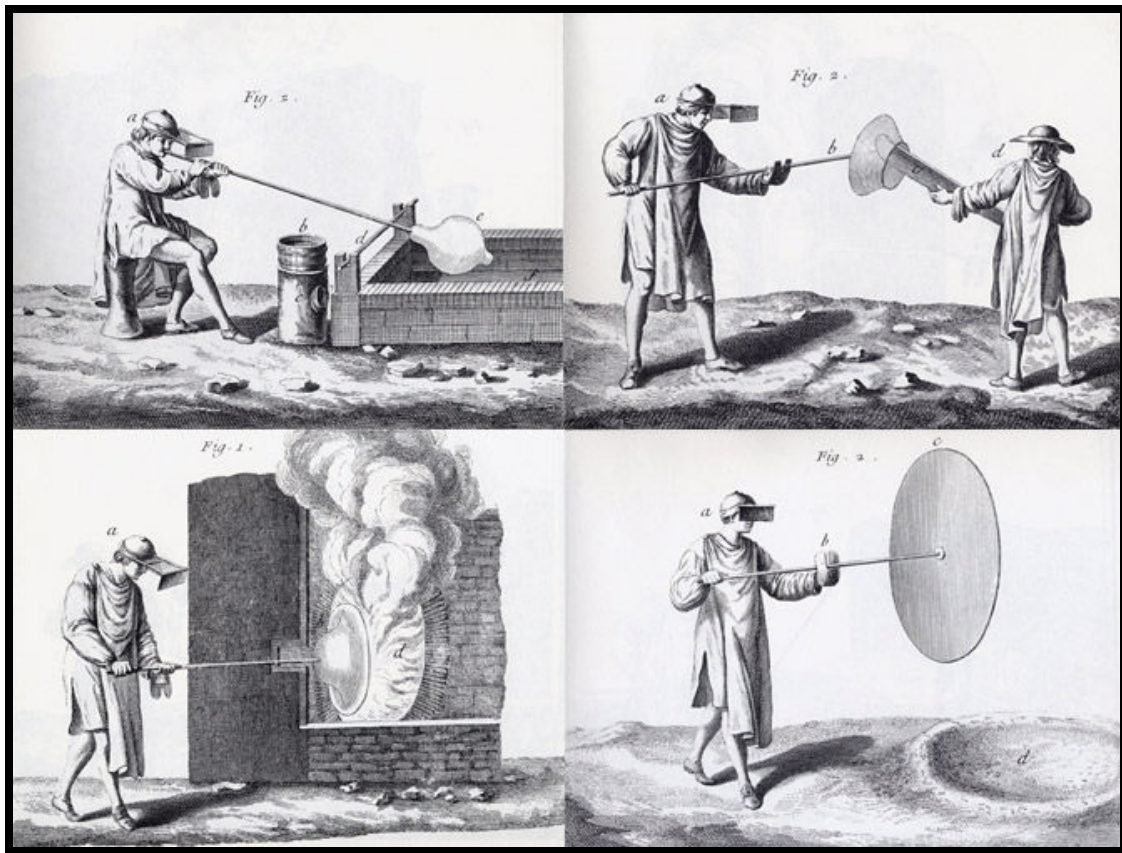


Figure 1-6 Manufacture of Crown Glass (www.rmears.co.uk 2010)

The third technique of flat glass manufacture was Cylinder Glass, this was particularly popular during the 17th century (Willmott 2002), this was the same principal as Broad Glass except that the glass was elongated over a large pit, in this way, the cylinders of glass could reach nearly 2m in length. The cylinder is again split lengthwise and flattened, but, unlike Broad Glass the cylinders were split after cooling. This method allowed the creation of larger window panes (Martlew 2008). It was the cylinder process which later became mechanised and during the 20th century the cylinders could get up to 12m in length although in the mechanised process the glass

was drawn vertically from the crucible (Martlew 2007). For more information on the mechanisation of glass manufacture see section 4.1.1.

1.4.2.5 18th Century Onwards

By the 18th and 19th centuries, new techniques for shaping glass had been invented, such as press moulding (see section 4.1.1 for more details on modern manufacturing techniques). This period also saw the great exhibition housed in the Crystal Palace which not only demonstrated the work of skilled glass artisans, but the building itself was constructed from 900,000 square feet of glass (Vose 1980). It was also around this time that new raw materials were developed and exploited, for example, in 1791 Nicolas Leblanc patented a method for producing synthetic soda for use as a flux in glass (Sutton 2006). Synthetic soda has been used in glass manufacture ever since (Dungworth 2008, pers. comm.). In France in 1824 a mechanical air pump was used for blowing glass bubbles and by 1854 Loup used the bait and compressed air method for making window glass cylinders (Silverman 1926). In 1903 the process was mechanised further with the invention of the Lubbers machine (Silverman 1926). Subsequent methods for the production of flat glass were invented and these remained the main production techniques until the development of the Float glass process (see section 4.3).

In more recent years, glass manufacturers have been working on developing smart glass and intelligent glass; this is where the glass is coated in order to be self-cleaning or to keep heat in during winter, and to keep the room cool during summer (www.pilkington.com 2010). Also, currently under development is the creation of ‘blast proof’ glass and ‘Hurricane proof’ glass, this is as a response to terrorist activity and natural disasters (MarketWatch 2008).

2 Analytical Techniques

This chapter will explain which analytical techniques are being used to analyse the glass samples, how the techniques work and why they were chosen. There are a number of analytical techniques available both forensic and archaeological with which to study glass. Not all of these techniques are suitable for use in provenancing glass. Therefore, the techniques outlined below have been specifically chosen because they will provide information about the chemical and physical properties of the glass which can be useful in determining the provenance.

2.1 Scanning Electron Microscopy (SEM)

“At the simplest level an SEM can be thought of as providing images of external morphology, rather similar in appearance to those formed by the eye” (Goodhew et al. 2001:1).

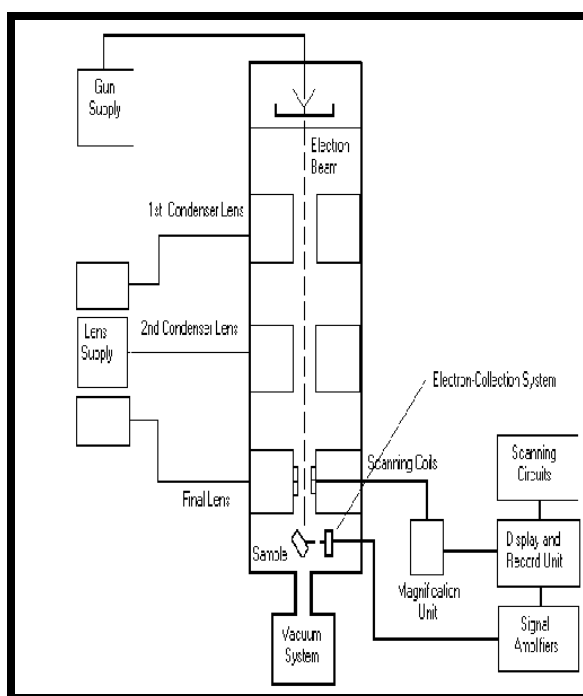


Figure 2-1 http://www.fisk.edu/~aburger/Published03_06/Instruments/SEM-EDS/sem-eds.html

Figure 2-1 shows the schematic of an SEM-EDS (Energy Dispersive Spectrometry). The sample, once prepared, is placed in an evacuated chamber. The chamber is evacuated because electrons are strongly scattered by gases (Goodhew et al.

2001). The electrons are emitted as a stream from an electron gun, and the beam is focussed using electromagnetic fields as lenses. The electron source or gun, used in an SEM is usually a tungsten filament thermionic emission type (Goodhew et al. 2001). This means that at temperatures in excess of 2700K a tungsten wire will emit both light and electrons (Goodhew et al. 2001). These electrons are then accelerated to create a beam. The diameter of the beam is dependent on the area of the filament which is emitting electrons (Goodhew et al. 2001). A field emission gun can also be used; this type of electron source will emit a brighter beam than the thermionic gun. A field emission source requires the use of ultra-high-vacuum (UHV) techniques. The vacuum in the gun must be lower (and is more expensive to achieve) than that which is used for thermionic guns (Goodhew & Humphreys 1988).

The SEM uses two types of electron to image the sample. Secondary electrons are those which escape from the specimen with energies below about 50eV (Goodhew et al. 2001). These electrons are relatively abundant and are the most commonly used. Backscattered electrons are not as numerous as secondary electrons, and most backscattered electrons have high energies (Goodhew et al. 2001). The electrons emitted from the sample are used to create images of the sample surface. The electron beam is scanned across the sample by the scanning coils, while a detector counts the number of low energy secondary electrons, or other radiation given off from each point on the surface (Goodhew et al. 2001).

Secondary electrons are detected by an Everhart-Thornley detector (Goodhew et al. 2001), this is a scintillator-photomultiplier system. The secondary electron strikes the scintillator and is converted into a photon. The photons are then passed through a tube to the photomultiplier which converts them into pulses of electrons (Goodhew & Humphreys 1988). These can then be amplified if necessary. This detector system is very efficient for flat specimens. The above mentioned detector can also detect backscattered electrons which may be travelling in the direction of the detector. Therefore, the signal collected by the Everhart-Thornley detector may not be purely secondary electrons. There are three types of detector which can be used for backscattered electrons. Scintillator detectors which are of a similar type to the Everhart-Thornley detector, have a rapid response time and may be used in conjunction with rapid scan rates; but, they are bulky and may restrict the working distance of the

microscope (Goodhew et al. 2001). A solid-state detector is a semi-conductor made of a thin flat plate. When electrons hit the semi-conductor they are separated and amplified (Goodhew & Humphreys 1988). The disadvantage of this type of detector is the relatively slow response time (Goodhew et al. 2001). The third type of detector used for backscattered electrons, is the 'through-the-lens' detector. This is where the SEM has specially designed objective lenses with very large magnetic fields and low spherical aberration. A scintillator detector is placed within the lens, and the sample within the strong magnetic field. The backscattered and secondary electrons pass upwards through the lens to the detector (Goodhew et al. 2001). Although this system has good collection efficiency, the size and movement of the sample may be restricted.

The electrons excite the sample in the evacuated chamber, causing it to give off X-rays (Shortland 2000). It is these X-rays which are measured and used to determine the chemical nature of the sample. In terms of measuring the X-ray spectra that are emitted from the samples, the energy or wavelength of the X-ray emitted describes which elements are present in the sample (a qualitative analysis) (Goodhew et al. 2001). Whereas the number of X-rays emitted per second will show how much of an element is present (quantitative analysis).

Many SEMs use an Energy Dispersive Spectrometer (EDS). The detector consisting of a piece of semi-conducting silicon or germanium is held in a position similar to that of the secondary electron detector (Goodhew et al. 2001). Both surfaces of the detector are covered with a thin layer of gold; this must be as thin as possible so that very few x-rays are absorbed in it. The detector is usually further protected by a thin window of beryllium or a polymer, but this too can absorb x-rays making it very difficult to detect the lighter elements (Goodhew et al. 2001). If the count rate is less than 1000 counts per second (cps) then most of the incoming pulses are processed, but if this rate rises then an increasing amount of the pulses are rejected (Goodhew & Humphreys 1988). The total time elapsed during an analysis consists of the time for which the detector was counting (live time) and the time for which the detector was ignoring the incoming x-rays (dead time). When determining the x-ray count rate for a given specimen, it is the number of counts collected during live time, not elapsed time that is required (Goodhew & Humphreys 1988).

The wavelength-dispersive spectrometer (WDS) works well in the areas which the EDS does not, for example, light element detection, peak separation, and peak to background ratio (Goodhew et al. 2001). With WDS only the x-rays of a chosen wavelength (specific element) are allowed to fall on a detector. The x-rays are diffracted by a crystal spectrometer (Goodhew et al. 2001). The design of the crystal spectrometer makes this technique expensive. The spectrometer usually holds between 2 and 4 crystals which can be interchanged automatically. The use of WDS can be very time consuming.

In order for accurate results to be gained from an SEM, the sample must first be flat and polished; this is so that the entire surface of the sample can be kept in focus. With any microscope, the image is only accurately in focus when the object lies in the appropriate plane (Goodhew & Humphreys 1988). Therefore, if part of the object being viewed lies above or below this plane, then the equivalent part of the image will be out of focus (Goodhew & Humphreys 1988).

2.1.1 SEM-WDS

SEM-WDS was used to analyse all of the Christ Church and the auto glass samples. In all, 91 samples of archaeological glass from the collection at Christ Church Cathedral (Table 2-1) were analysed. These samples were all dated based on an art-historical assessment of the images or paint work depicted on the front of the fragment. In Table 2-1 the different art-historic dates have been reflected in the colour of the sample name; blue represents the work of Price dated 1696, pink indicates Victorian or later work, red represents Van Linge which dates 1630-1640, and turquoise indicates Other, where the date is questioned or unknown. One sample thought to be Medieval in date has also been assigned to the 'Other' category, because it was the only positively identified Medieval fragment. In terms of the auto glass case study, 24 samples of modern automotive glass were analysed (Table 2-2). In relation to Table 2-2 the DOT No., which is an actual number stamped on the window, relates to the location of the plant in which the glass was made.

Sample No.	Art-historic Date	Colour	Window
CCOX01	Victorian	Colourless	
CCOX02		Colourless	

CCOX03		Colourless	
CCOX04		Colourless	
CCOX05		Colourless	
CCOX06	Van Linge (1630s)	Colourless	
CCOX07		Colourless	
CCOX08	Van Linge (1630s)	Colourless	
CCOX09	Van Linge (1630s)	Colourless	
CCOX10	Van Linge (1630s)	Colourless	
CCOX11	Van Linge (1630s)	Colourless	
CCOX12	? Price	Colourless	
CCOX13		Colourless	
CCOX14		Colourless	
CCOX15	? Van Linge	Colourless	
CCOX16		Colourless	
CCOX17	? Van Linge	Colourless	
CCOX18	? Van Linge	Colourless	
CCOX19	? Van Linge	Colourless	
CCOX20		Colourless	
CCOX21		Colourless	
CCOX22	? Van Linge/Price	Colourless	
CCOX23	Victorian	Colourless	
CCOX24	Victorian	Colourless	
CCOX25	Victorian	Red Flash	
CCOX27	Victorian	Red Flash	
CCOX28	Victorian	Yellow	
CCOX29	Victorian	Green	
CCOX30	? Victorian	Red Flash	
CCOX31	Victorian	Red Flash	
CCOX32	? Victorian	Purple	
CCOX33		Dark Blue	
CCOX34	? Van Linge	Colourless	
CCOX35		Colourless	
CCOX36	? Van Linge	Colourless	
CCOX37	Van Linge (1630s)	Colourless	
CCOX38		Colourless	
CCOX39	? Van Linge	Colourless	
CCOX40	? Van Linge	Colourless	
CCOX41	? Van Linge	Colourless	
CCOX42	Van Linge (1630s)	Colourless	
CCOX43	Van Linge (1630s)	Colourless	
CCOX44	Price (1696)	Colourless	
CCOX45	Van Linge (1630s)	Colourless	
CCOX46	Van Linge (1630s)	Colourless	
CCOX47	Van Linge (1630s)	Colourless	
CCOX48	Van Linge (1630s)	Colourless	
CCOX49	Van Linge (1630s)	Colourless	
CCOX50	? Price	Colourless	
CCOX51	? Price	Colourless	
CCOX52	Van Linge (1630s)	Colourless	
CCOX53		Colourless	
CCOX54		Colourless	
CCOX55	Van Linge (1630s)	Colourless	
CCOX56	? Price	Colourless	
CCOX57	Price 1696	Colourless	
CCOX58	? Van Linge	Colourless	

CCOX59		Colourless	
CCOX60	? Van Linge	Colourless	
CCOX61		Colourless	
CCOX62		Colourless	
CCOX63	Van Linge (1630s)	Colourless	
CCOX101	Van Linge (1630s)	Colourless	Arms of King Family
CCOX102	Medieval	Colourless	Latin Chapel
CCOX103	Victorian	Colourless	
CCOX104	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX105	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX106	Price 1696	Colourless	Wolsey Crest
CCOX107	Price 1696	Colourless	
CCOX108	Van Linge (1630s)	Colourless	Arms of Burton
CCOX109	Van Linge (1630s)	Colourless	Arms of Thomas
CCOX110	Price 1696	Colourless	Arms of Birch
CCOX111	Price 1696	Colourless	Nativity
CCOX112	Price 1696	Colourless	
CCOX113	Price 1696	Colourless	
CCOX114		Colourless	
CCOX115		Colourless	
CCOX116	Price 1696	Colourless	
CCOX117	Price 1696	Colourless	
CCOX118	Price 1696	Colourless	
CCOX119	Price 1696	Colourless	
CCOX120	Price 1696	Colourless	
CCOX121	? Van Linge	Dark Blue	
CCOX122	? Price/Oliver	Colourless	
CCOX123	? Van Linge/Victorian	Light Blue	
CCOX124		Colourless	
CCOX125	Victorian	Purple	
CCOX126	Price 1696	Colourless	
CCOX127	Price 1696	Colourless	
CCOX128	Victorian	Red Flash	
CCOX129	Price 1696	Colourless	Nativity

Table 2-1 Table of samples from Christ Church showing sample number, date, colour and location if known. The sample numbers are in the colour that defines a particular group: Price, Victorian, Van Linge, Other

Sample No.	Make	Model	Date (of car)	Glass Manufacturer	DOT No. Location	Location
AuAUD02	Audi	A4				Rear Driver
AuBMW02	BMW		1991			Front Passenger
AuCIT01	Citroën	Zantia	2000			Windscreen
AuCIT02	Citroën	AX		PPG	France	Front Passenger
AuDAE01	Daewoo	Luganza	1999			Windscreen
AuFIA01	Fiat	Tipo	1988			Windscreen
AuFIA02	Fiat	Tipo	1989			Sun Roof
AuFOR01	Ford	Focus				Windscreen
AuFOR02	Ford	Escort	1994			Rear Passenger
AuFOR03	Ford	Transit	1996			Front Passenger
AuFOR04	Ford	Fiesta		Pilkington	UK	Front Passenger

AuFOR05	Ford	Transit		Pilkington	UK	Front Passenger
AuNIS01	Nissan	Sunny		Central Glass Co.	Japan	Front Passenger
AuREN01	Renault	Clio	1999			Windscreen
AuREN02	Renault		1992			Windscreen
AuROV01	Rover		1993			Front Passenger
AuROV02	Rover	Metro		Pilkington	UK	Front Passenger
AuTOY01	Toyota	Carina	1992			Windscreen
AuVAU01	Vauxhall	Corsa				Windscreen
AuVAU02	Vauxhall	Astra	1997	Guardian	USA	Windscreen
AuVW01	VW	Sharan	1997			Windscreen
AuVW02	VW		1993			Rear Windscreen
AuVW03	VW	Sharan	1998			Rear Passenger
AuVW04	VW	Golf	1988	Saint Gobain	Germany	Front Passenger

Table 2-2 Table of automotive samples showing sample number, make, model, age of car, glass manufacturer, location of glass plant, and location of sample on vehicle

This technique was chosen in order to determine the major and minor elements in the glass. The use of a WDS offers a more accurate determination of the elemental concentrations in the glass than EDS. In these analyses 22 oxides were determined Na_2O , SiO_2 , MgO , Al_2O_3 , TiO_2 , P_2O_5 , K_2O , CaO , SO_3 , Cl , Cr_2O_3 , Fe_2O_3 , MnO , CoO , NiO , CuO , ZnO , SrO , SnO , Sb_2O_5 , BaO , PbO . Of these, the levels of Cr_2O_3 , CoO , NiO , ZnO , SrO and SnO in the glasses all proved to be below the detection limits of the machine. Generally, anything that is below 0.05% is below the detection limits of this machine and therefore would need to be confirmed via a technique suitable for determining trace elements such as LA-ICP-MS.

The samples of glass were mounted on their cross-section in Struers Specifix-20 resin. The 25mm blocks each contained up to 6 glass samples, and these were ground using silicon-carbide paper from 250 grit down to 4000 grit. The blocks were then polished using $3\mu\text{m}$ and then $1\mu\text{m}$ diamond suspension fluid. For use in the SEM the blocks were carbon coated, this was polished off before the samples were then analysed with LA-ICP-MS. The SEM-WDS analyses were carried out on a Jeol Superprobe JDCA 8800R at Begbroke Science Park, Oxford, and the SEM-WDS was run at 20keV and 20nA. The Corning glass standards were used throughout the run. The relative analytical accuracy attained using the Corning glass standards was for major oxide components, 4% Na_2O , 1% SiO_2 , 3% K_2O , 5% CaO and 2% PbO . For minor elements

the levels of accuracy were, 2% MgO, 1% Al₂O₃, 10%Fe₂O₃ and CuO (Henderson 1988; Shortland & Eremin 2006; Shortland 2002).

2.2 Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

“The technique of inductively coupled plasma (ICP) spectroscopy has expanded and diversified in the form of a mini-revolution in the last forty years. What was essentially an optical emission spectroscopic technique for trace element analysis has expanded into a source for... mass spectrometry, capable of detecting elements at sub-ppb (ng ml⁻¹) levels with good accuracy and precision” (Dean 2005: xiii).

Laser Ablation Inductively Coupled Plasma Mass Spectrometry or LA-ICP-MS is known as a hyphenated technique, laser ablation is the means of sample introduction, the inductively coupled plasma ionises the sample and the mass spectrometer determines the elements present based on the masses of different ion species (Pollard & Heron 1996). ICP-MS was first commercialised in 1983 and since then has become the method of choice for fast, trace level elemental analysis for a wide range of materials (Pollard et al. 2007). The main difference between solution ICP-MS and LA-ICP-MS is the means of sample introduction. During laser ablation, part of the solid sample is volatilised by the laser and transported by the argon flow to the ICP torch, where the sample is then ionised for mass spectrometric elemental analysis (Pillay 2001). Figure 2-2 shows the schematic of a LA-ICP-MS.

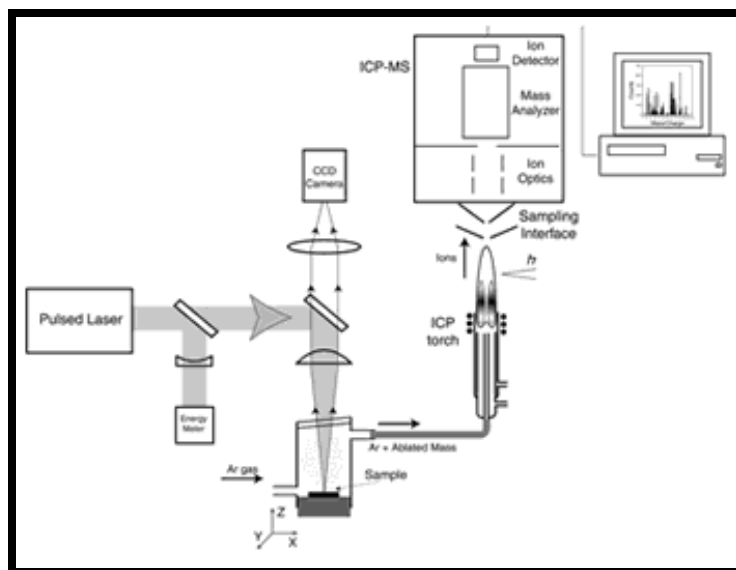


Figure 2-2 LA-ICP-MS taken from www.appliedspectra.com/LaIcpMs.html

LA-ICP-MS combines the advantages of being virtually non-destructive with high sensitivity, and high analytical precision and accuracy, it is also a relatively rapid technique (Shortland et al. 2007). Laser ablation is also beneficial in that it can be applied to any solid sample, there are no sample size requirements (other than fitting into the sample chamber), there is no sample preparation involved, and spatial characterisation information is available (Dean 2005), the latter being lost during solution ICP-MS (Pollard et al. 2007).

The most common laser used for LA-ICP-MS is the Nd:YAG laser. Nd:YAG laser applications are often used in the near infrared at 1064nm (Dean 2005), but in the case of archaeological samples, chemical fractionation was found to be a problem and so samples are usually ablated using an ultraviolet Nd:YAG laser at 266nm (Pollard et al. 2007). As mentioned before, the focused and pulsed laser beam ablates a discrete area of the sample, the products of which are carried in a stream of argon directly into the plasma torch (Pollard et al. 2007). A typical plasma torch consists of three concentric silica tubes, with copper coils around the outside at the top (Pollard & Heron 2008). Power input to the ICP is achieved through the copper coil, typically in the range 0.5-1.5kW at a frequency of 27 or 40MHz (Dean 2005). The argon gas which forms the plasma is injected vertically through the central tube, a larger volume of gas spirals up between the outer casing acting as a coolant (Pollard & Heron 2008). The coolant gas maintains the plasma and also acts as a thermal barrier between the plasma and the torch, thereby preventing the torch from melting (De Muynck 2008). The plasma is

ignited by a spark (Dean 2005). When ignited the plasma passing through the centre of the torch glows white-hot, it is then lifted away from the silica tubing by the toroidal flow of the cooling gas (Pollard & Heron 2008). The temperature of the torch (up to 10,000°C) is sufficient to ionise 50% of the atoms in the sample (Pollard & Heron 2008).

ICP-MS works by efficient coupling of an ICP working at high atmospheric pressure, with a MS operating under high vacuum (Dean 2005). The result of the complex interface between the plasma torch and the MS is a stream of positive ions entering a high vacuum mass spectrometer (Pollard et al. 2007). The interface consists of a sampling cone and a skimmer (expansion zone); when the plasma gas enters the space between the sampling cone and the skimmer, the ions, electrons and neutral species are expanded due to the high vacuum in the expansion zone. At every vacuum stage, residual components are pumped away (De Muynck 2008). Positively charged ions are then focused and directed towards the mass spectrometer (De Muynck 2008). Mass spectrometry works on the principle that electrically charged atoms and molecules can be separated on the basis of their different atomic masses (Pollard & Heron 1996). There are a variety of types of mass spectrometer which can be coupled with ICP techniques. As previously mentioned, all mass spectrometers are able to separate ions on the basis of their mass-to-charge ratio (m/z).

The first type of mass spectrometer to be used commercially with ICP was the quadrupole mass spectrometer (Dean 2005), as illustrated in Figure 2-3.

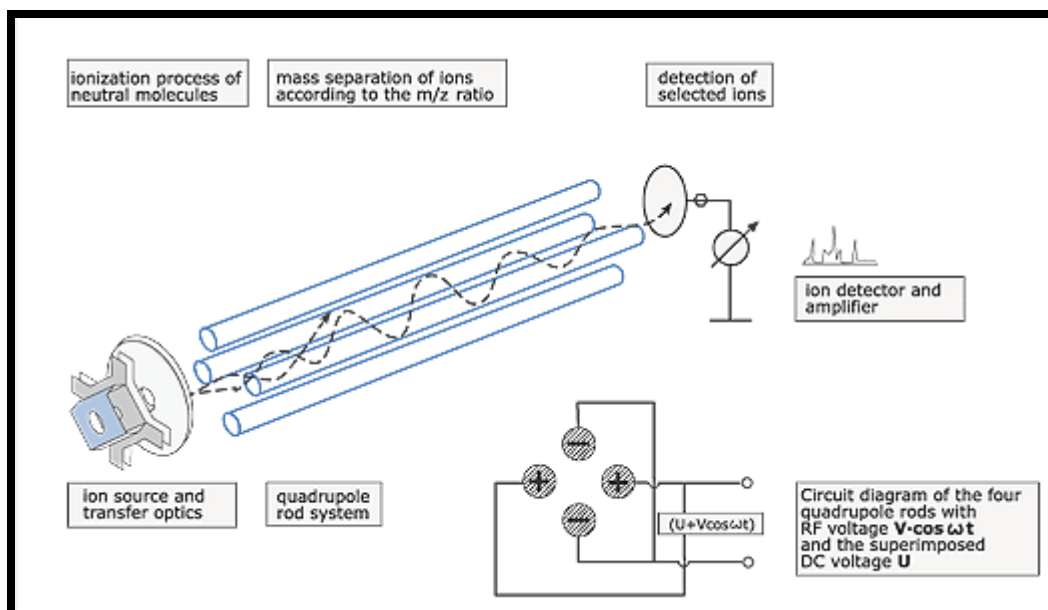


Figure 2-3 <http://www.in-process.com/2/massenspektrometrie/quadrupolmassenspektrometer.html>

The quadrupole analyser consists of four straight metal rods parallel to each other around a central axis (Dean 2005). Direct current (DC) and radio frequency (RF) voltages are applied to opposite pairs of rods. Ions entering the quadrupole are subjected to oscillatory paths by the RF voltage. By selecting the appropriate RF and DC voltages, only ions of a given mass/charge ratio will make it to the end of the rods (Dean 2005). By continuously changing the DC and RF values multi-element analysis can be conducted. A time-of-flight (ToF) mass spectrometer uses an applied accelerating voltage and the resultant different velocities of ions as the basis of its ion separation (Dean 2005). This method of measuring the mass-to-charge ratio monitors the ‘time of flight’ of an ion as it passes through a detector (Pollard et al. 2007). The lighter ions travel faster than the heavier ions down the drift tube from source to detector (Dean 2005).

Because of the high sensitivity of the technique, the results of LA-ICP-MS analysis provides accurate data regarding minor and trace elements (Table 2-3), highlighting the small compositional differences between samples (Shortland et al. 2007). LA-ICP-MS can also be used to give information about isotopic ratios in samples (Pillay 2001).

Amount of analyte/sample	From nanogram to femtogram range	From milligram to microgram range
Precision of trace element determination	ICP-MS	LA-ICP-MS
Spatially resolved analysis	Often simple (expensive with matrix separation)	Lateral resolution $< 10 \mu\text{m}$
Depth profiling of thick layers	Excellent	Difficult, often required
Time consumption per step	0.005 sample preparations (solutions)	0.0002 sample preparations (solids)

Contamination risk	High	Low
Limitations	Interferences	Interferences, inhomogeneity

Table 2-3 Precision of the ICP technique (Becker 2002: 1807)

LA-ICP-MS offers spatial resolution of between 10-100µm, sub-ppm detection limits and rapid analysis times of typically around ≤ 5 mins can be achieved (Norman et al. 1998). While quantitative analysis is possible with LA-ICP-MS, as we can see from the above table it is difficult. It is suggested that the results of the LA-ICP-MS could be analysed with Principal Component Analysis (PCA), this is suggested as being able to eliminate the needs for elemental calibration (Bajic et al. 2005).

As well as the detection limits offered by these techniques, we must also be aware of some of the interferences that can cause problems. These interferences can be either *spectral* or *non-spectral*. Spectral interferences can occur as a result of the overlap of atomic masses of different elements (Dean 2005). This can be a result of the acids used to prepare the sample and/or the argon plasma gas. In order to prevent spectral interference the plasma can be operated in ‘cold plasma’ or ‘cool plasma’ conditions, this means the plasma is operated at low power and high injector flow rates; alternatively, plasma relying on a gas other than argon could be used (De Muynck 2008). Non-spectral interferences refer to matrix induced changes in the signal intensity that are unrelated to the presence of the spectral component (De Muynck 2008). Non-spectral interferences result in signal enhancement or depression with respect to the atomic mass (Dean 2005).

“The application range of ICP-MS is immense and this technique has become a valuable partner throughout the analytical world, for both academic and industrial purposes” (De Muynck 2008: 9).

2.2.1 LA-ICP-MS

LA-ICP-MS was also used on both the Christ Church samples and the automotive samples, but, due to the expensive nature of the technique the Christ Church samples were limited to 24 which had been assigned to a definite art-historic period or artist. The samples chosen from the Christ Church fragments are listed in Table 2-4, the samples represented those which were definitely by Price (1696), those which were

definitely by Van Linge (1630s) and those which were thought most likely to be by Van Linge.

Sample No.	Art-historic Date	Colour	Window
CCOX09	Van Linge (1630s)	Colourless	
CCOX10	Van Linge (1630s)	Colourless	
CCOX11	Van Linge (1630s)	Colourless	
CCOX15	? Van Linge	Colourless	
CCOX19	? Van Linge	Colourless	
CCOX36	? Van Linge	Colourless	
CCOX37	Van Linge (1630s)	Colourless	
CCOX40	? Van Linge	Colourless	
CCOX42	Van Linge (1630s)	Colourless	
CCOX45	Van Linge (1630s)	Colourless	
CCOX48	Van Linge (1630s)	Colourless	
CCOX58	? Van Linge	Colourless	
CCOX101	Van Linge (1630s)	Colourless	Arms of King Family
CCOX104	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX105	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX108	Van Linge (1630s)	Colourless	Arms of Burton
CCOX109	Van Linge (1630s)	Colourless	Arms of Thomas
CCOX113	Price 1696	Colourless	
CCOX116	Price 1696	Colourless	
CCOX117	Price 1696	Colourless	
CCOX118	Price 1696	Colourless	
CCOX119	Price 1696	Colourless	
CCOX120	Price 1696	Colourless	
CCOX121	? Van Linge	Dark Blue	

Table 2-4 Table of Christ Church samples analysed by LA-ICP-MS

All 24 of the auto samples were subjected to trace elemental analyses. The LA-ICP-MS analysis looked at 45 trace elements within the glass (Li, Be, B, Al, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Rb, Sr, Y, Zr, Ag, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Pb, Bi, Th, U). This technique was chosen because it is a virtually non-destructive method of determining the trace elements within the sample in a fully quantitative way.

The same sample blocks were used for the ICP analyses as were used for the SEM-WDS, although, the carbon was polished off before the samples were analysed with LA-ICP-MS.

The LA-ICP-MS analyses were carried with a New Wave UV-213 laser ablation system in conjunction with an Agilent 7500a ICP-MS, at the Open University in Milton Keynes. Samples were ablated under an argon atmosphere using an 80µm laser spot diameter operated at 10Hz with a laser power of $\sim 7 \text{ Jcm}^{-2}$. All of the samples were analysed in spot mode. The ablated material was then transported to the plasma source

using the gas flow control system on the 7500a at a flow rate of approx 1.21min^{-1} and the plasma was operated at a power of 1400W. The conditions resulted in a beam with an intensity of $\sim 10^3$ cps/ppm with a Th^+/ThO^+ ratio of $>0.5\%$. The signals from the ablated samples were recorded in time-resolved mode over a period of $\sim 240\text{s}$, during the first 120s of which the shutter remained closed to allow the measurement of the ‘gas blank’. The signals were subsequently interpreted using the ‘GLITTER’ software package with Ca used as the internal standard element. The analyses were calibrated against the NIST SRM 610 glass reference material, doped with a nominal concentration of 500ppm for most trace elements, and using the consensus values. Measurements were also made of the NIST SRM 612 and the Corning A standard. These latter repeats allowed for the calculation and correction of machine drift (Shortland et al. 2007).

2.3 Isotopes

“Isotope geology is concerned with the measurement and interpretation of the variations of the isotope composition of certain elements in natural materials” (Faure & Mensing 2005: 3).

Isotopic ratios of specific elements vary with age and with the type of raw material in which the element is located (Degryse et al. 2006), this signature often remains the same, even when the raw material is made into something else, for example, when lime is added to glass (Henderson et al. 2005). This therefore means that isotopes can be used as tracers to show the potential origin of artefacts (Degryse et al. 2006). The term ‘isotopes’ is derived from two Greek words meaning ‘same place’, this is referring to their position in the periodic table (Putman 1965). The number of protons in the nucleus of an atom are specific to a particular element, but most elements can exist with two or more different numbers of neutrons. These are known as isotopes of an element (Pollard et al. 2007).

Around 270 of nearly 2500 known nuclides are stable (Faure & Mensing 2005) to be considered stable the half-life of the element is more than 10^9 years (De Muynck 2008) and most stable nuclides have even numbers of protons and neutrons (Faure & Mensing 2005). Although, as the atomic mass increases, the stable neutron/proton ratio

can also increase (Dickin 2005). Unstable isotopes undergo radioactive decay until the isotope is transformed into another more stable nuclide (Duncan & Cook 1968). The radioactive decay of the nucleus is a random process, but the decay of a particular element is known by its ‘half-life’, this is the time taken for half of the original material to change into another element by radioactive decay (Pollard et al. 2007). The time it takes for this to happen can vary from a few seconds to billions of years.

The half-life ($T_{1/2}$) can be calculated as

$$T_{1/2} = \frac{0.693}{\lambda}$$

where λ is the decay constant (Pollard et al. 2007), which states the probability that the given atom of a radionuclide will decay within the stated time (Dickin 2005).

Different abundances of each isotope occur and it is the different ratios of these isotopes which are measured to determine the ages of rocks and minerals (Aitken 1990). By comparing the ratios of isotopes extracted from an object, it may be possible to identify the probable geographic location from which the raw material came (Brill et al. 1979). Isotopes are measured using mass spectrometers, and until the recent development of high precision multi-collector inductively coupled plasma mass spectrometers (MC-ICP-MS), the standard tool for the measurement of isotopes was by thermal ionisation mass spectrometry (TIMS) (Pollard et al. 2007). With TIMS analysis the sample is evaporated to dryness and deposited on a refractory metal wire, usually tantalum, which is then loaded into the MS and electrically heated to cause volatilization (Pollard & Heron 2008). The manner by which the sample is deposited and then heated has a major effect on the efficiency of the analysis (Dickin 2005). TIMS can have multi or single filaments. Once the positive ions have been injected into the MS, the beam is separated into its component masses deflecting the ions using a magnetic field. The angle of deflection of the ions depends upon their mass, the heavier ions being deflected less (Pollard & Heron 2008). The ions strike the detector, the resulting current is passed through a large resistor, where the voltage is measured. The magnitude of the current flowing is directly proportional to the number of ions being received at the detector (Pollard et al. 2007). In this way, it is possible to use multiple

detectors, each angled slightly differently in order to simultaneously detect the different isotope abundances. Thereby, providing ratios of the isotopes present in the sample.

One of the problems associated with isotope analysis is that of fractionation. During TIMS analysis the lighter isotopes are preferentially released from the hot filament (Dickin 2005), the magnitude of the effect is dependent on the mass difference between the isotopes (Pollard et al. 2007). The continual process of fractionation starts to 'use-up' the lighter isotopes on the filament, therefore the isotopic composition of the sample becomes progressively heavier. This is known as the 'reservoir effect' (Dickin 2005) and the magnitude of this effect could yield errors of up to 1% in the measured isotope ratio. The advantage of using a double or triple filament machine is the ability to independently control vaporisation and ionisation (Rao et al. 2007). Therefore, multiple element TIMS can be used to compensate the effects of fractionation that may occur in single element TIMS.

The technique of multi-collector-ICP-MS (MC-ICP-MS) was specifically developed to overcome some of the problems that occurred with TIMS. In TIMS thermal ionisation is achieved for only a limited number of elements, whereas by using an ICP as an ion source virtually all the elements in the periodic table are accessible to isotopic analysis (De Muynck 2008). In MC-ICP-MS the detector uses multiple Faraday Cups which allows the simultaneous collection of separated isotopes. The multi-collection approach cancels out the effects a 'noisy' signal on the isotope ratio measurement (De Muynck 2008). The interest in MC-ICP-MS instrumentation is largely based on the high precision and extreme versatility of this technique (De Muynck 2008).

2.3.1 Isotopic Analysis

Only the automotive glass samples were sent for isotope analysis due to the cost of using the technique. There is a lot of literature published on the use of isotopes on archaeological glass (Henderson et al 2005; Degryse et al 2006; Freestone et al. 2003), whereas, this technique has not been tried on modern glass samples before. In all, 19 samples were chosen (Table 2-5), these were all samples that had previously been analysed by RI and represented a selection of windscreens and side windows. The

samples were all analysed to determine the Sr and Nd isotopic composition as this imparts information relating to the calcium and sand sources used in the glass.

Sample No.	Make	Model	Date (of car)	Glass Manufacturer	DOT No. Location	Location
AuAUD02	Audi	A4				Rear Driver
AuBMW02	BMW		1991			Front Passenger
AuCIT01	Citroën	Zantia	2000			Windscreen
AuCIT02	Citroën	AX		PPG	France	Front Passenger
AuFIA01	Fiat	Tipo	1988			Windscreen
AuFIA02	Fiat	Tipo	1989			Sun Roof
AuFOR01	Ford	Focus				Windscreen
AuFOR02	Ford	Escort	1994			Rear Passenger
AuFOR03	Ford	Transit	1996			Front Passenger
AuFOR04	Ford	Fiesta		Pilkington	UK	Front Passenger
AuFOR05	Ford	Transit		Pilkington	UK	Front Passenger
AuNIS01	Nissan	Sunny		Central Glass Co.	Japan	Front Passenger
AuROV01	Rover		1993			Front Passenger
AuROV02	Rover	Metro		Pilkington	UK	Front Passenger
AuTOY01	Toyota	Carina	1992			Windscreen
AuVW01	VW	Sharan	1997			Windscreen
AuVW02	VW		1993			Rear Windscreen
AuVW03	VW	Sharan	1998			Rear Passenger
AuVW04	VW	Golf	1988	Saint Gobain	Germany	Front Passenger

Table 2-5 Table of automotive samples sent for isotope analysis

The samples of glass were crushed by hand in a mortar and pestle to a fine powder, c. 2grams of powder of each sample was sent to Ghent University for Sr-Nd analysis. Powdered samples were digested in HF:HNO₃ in a ratio of 3:1, each sample was left in a sealed beaker on a hot plate at 110°C over night and then the sample was dried; the HF was used in order to dissolve the Si in the samples. Next, the samples were put into a mix of Aqua regia, HCl:HNO₃ in a ratio of 3:1 and again left on a hot plate at 110°C over night, the samples were then dried; this step was necessary in order to dissolve any remaining metals in the samples. The Sr and Nd fractions were then isolated from the samples using special resins (EICHROM Sr and EICHROM Nd resin). The analyses of the samples were carried out on a Thermo Scientific Neptune multi-

collector ICP-MS instrument, following the procedure set out in De Muynck et al (2009). The standards used were NIST SRM 987 for the Sr isotopes and La Jolla Nd standard for the Nd isotopes. Repeated measurements of the NIST SRM 987 over the duration of the study yielded an average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.710260 ± 0.000067 (0.005%). Repeated measurements of the La Jolla Nd standard over the duration of the study yielded an average $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.512400 ± 0.00001 (better than 0.005%).

2.4 Refractive Index (RI)

“When choosing an analytical method for glass analysis for forensic purposes one should take into account that the amount of material is usually very small, and the material has to be preserved to avoid the destruction of evidence. So the method chosen should be non-destructive” (Zadora 2007: 174).

This is the most common argument in favour of the use of either refractive index (RI) or density as a method of glass analysis in forensic laboratories. The non-destructive nature of the technique means that analyses are repeatable, even on very small fragments. Refractive Index is the ratio between the velocity of light in a vacuum to the velocity of light in a medium (Curran et al. 2000). The refraction of light occurs because the light is slowed when it enters the medium, in this case glass. Because the medium always slows the velocity of light, the RI is always greater than 1 (Foster and Freeman). Figure 2-4 illustrates what happens to light when it passes through a second medium.

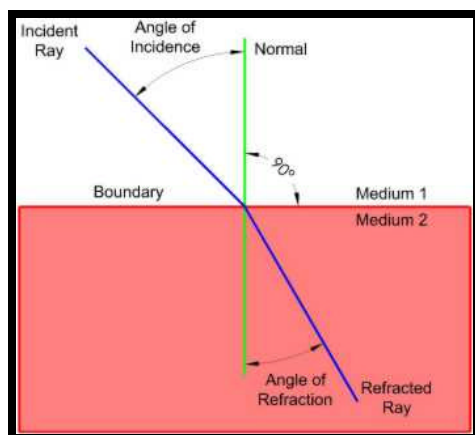


Figure 2-4 <http://www.mysundial.ca/tsp/images/refraction.jpg>

The RI of materials varies with the wavelength of light. The RI is generally smaller for longer wavelengths causing an effect known as 'dispersion' (Foster and Freeman). Dispersion is where different wavelengths of light are refracted at different angles causing a beam of white light to become separated or dispersed into component colours (Foster and Freeman). Because of this it is important to note at what wavelength RI measurements are being taken, in forensic work this is usually 589nm in sodium D light.

The mineralogist Becke first noted the phenomenon while analysing geological samples in 1892. While using a microscope he observed a bright line on the inside edge of the mineral section he was looking at, and that it had a higher RI than the surrounding areas (Curran et al. 2000). He also noted that when the objective on the microscope was raised, the line moved in the direction of the mineral with the higher RI. The Becke line is a function of how light behaves at the boundary between two components with different RIs. During the 1930s Emmons described the variance of RI with temperature, during the 1970s Mettler developed a hot-stage, which allowed good control of the temperature and was typically used in conjunction with a phase contrast microscope. During the 1980s Foster and Freeman developed the first Glass Refractive Index Measurement (GRIM) machine (Curran et al. 2000). The GRIM uses a phase contrast microscope at a fixed wavelength of 589nm. The GRIM is the method of choice for the measurement of RI in forensic laboratories. Repeat measurements can produce results with a standard deviation of 0.00003 over a five day period (FBI 2005b). The other most common method of RI measurement used in forensic labs is the 'immersion method' (Sanger 1985). This is where the glass particles, typically below 1mm in length, are placed on a cavity slide, and immersed in inert oil and viewed under a microscope. The temperature of the immersion medium and the sample are changed by the use of a heating stage. In the latter method the variation of the RI of the oil with a changing temperature is known and this is used to deduce the RI of the glass sample, when the 'match temperature' is found. The precision in this technique can be as great as ± 0.00002 (Sanger 1985). Both of these techniques rely on well calibrated immersion oils, where the RIs at different temperatures are well known.

RI measurements are often used not only to discriminate between the suspect and the control glass samples, but also to determine the classification of the glass, i.e.

window glass, container glass, or auto glass. Modern window glass typically falls in the range 1.5155-1.5175, while container glass has a RI between 1.5190-1.5210 (Harrison et al. 1985). Forensic examiners admit that the classification system for glass is rather simple, and that it may be imperfect. It is generally accepted that within the RI range examined, if the glass has high magnesium content it is more likely to be window glass and low magnesium content suggests non-window glass. These groupings are arbitrary, and often subjective, if different manufacturers with different chemical formulations are used to produce these glasses, then they are unlikely to form a coherent group (Hickman 1981). Glasses most likely to be encountered in forensic casework are colourless with RIs in the range 1.5125-1.5250.

Glass of RI 1.5200 is commonly found on clothing but, control glasses of this RI are relatively rare (Harrison et al. 1985). Since 1980 there has been an observed narrowing of the spread RI values, and it has become necessary to seek for more discriminatory measures that can be used to compare fragments of glass having indistinguishable RI values (Koons & Buscaglia 2001). It is argued that multi-element discrimination shows a significant improvement in discrimination statistics over using only RI measurements (Becker et al. 2004). *“Nevertheless, results of classification of unknown glass fragment solely on the base of elemental composition, should be treated very carefully as due to the possible legal consequences of misclassification”* (Zadora 2007: 185).

2.4.1 RI

Refractive Index (RI) analysis was chosen as an example of a forensic method of glass analysis. The same 19 samples of automotive glass were chosen for analysis as were used in the isotopic analyses (Table 2-5). These samples covered a range of car and glass manufacturers as well as including windscreens and side windows. Also, 10 samples of archaeological glass (Table 2-6) were chosen for analysis, these covered a range of periods; Egyptian, Roman, Medieval, 17th Century, and Victorian (everything bar the Roman and Egyptian samples coming from the Christ Church collection).

Sample	Date
COP9	Egyptian
UPP3	Egyptian
PD26	Roman
PD29	Roman
CCOX102	Medieval
CCOX123	Med/Vic
CCOX01	Victorian
CCOX103	Victorian

Table 2-6 Samples of Archaeological glass used for RI analysis

The reason a selection of archaeological periods were covered rather than just glass from the cathedral, was so the usefulness of the technique as a screening tool for archaeological work could be assessed. The analyses of the samples occurred at the University of West England (UWE), using a GRIM 3. The samples for RI analysis were each washed with ethanol and dried. The samples were then broken in a mortar and pestle to ensure a fresh edge could be analysed. Fragments were then placed in oil on a microscope slide and covered with a cover slip. The samples of auto glass were all analysed using Locke Scientific Silicone Oil B which has a refractive index range of 1.520 in sodium D light at 65°C - 1.537 in sodium D light at 20°C. The archaeological samples were analysed using Locke Oils A and B and Cargille RI Liquid Series A. In terms of the auto glass analyses, each sample was crushed and made into four slides, each slide had three fragments measured, and each fragment had measurements taken from three or four points. The measurements had a precision of ± 0.0001083 .

3 Study 1: Glass from Christ Church Cathedral, Oxford

“Oxford has been justly called a city of palaces; no town in England, and we may add in the world, can pretend to be its competitor” (Walcott 1858: 73).

Many authors have spoken highly of Oxford and its beauty, especially in relation to its architecture; the city has been described by some as the culture of the country (Dougill 2001). The wealth of architectural glass in and around Oxford is well known, it is believed to be unique in its amount of pre-Victorian stained glass (Sherwood & Pevsner 1975). It is the stained glass from the collection at Christ Church Cathedral which was sampled for this case study. Glass from Christ Church was chosen because in 2002 over 9000 fragments of stained and painted glass were discovered in a coal bunker beneath Tom Quad. The majority of these fragments appeared to belong to the Van Linge window scheme which was present in the cathedral during the 17th century but about which very little is known. The cathedral records say little about the windows; there is virtually no mention of the changes that occurred or the work that was commissioned in terms of the glass, yet the other work that was undertaken during this period such as the wood panelling or the laying of a marble floor are fully documented (Power & Shortland 2007).

This research offered an opportunity to study some of the fragments of glass in the collection along with the *in-situ* windows, using both forensic and archaeological analytical techniques. A large number of colourless glass samples were available for analysis representing most periods of the cathedral’s window history. The glass fragments sampled were in the first instance dated to a specific period of the cathedral’s history based on an art-historic interpretation of the style of painting on the glass. This meant that several questions could be answered in relation to the glass, for example, could all the fragments be grouped based on the chemical composition and did this composition relate to the periods of glass manufacture? Based on this approach, an attempt was made to determine whether periods of restoration of the windows could also be determined, through a combination of chemical analysis and art-historic analysis. A study of the fragments meant that attempts could be made at reconstructing the Van Linge window scheme. By ascertaining which windows the fragments came

from, the images on the fragments could be compared with existing Van Linge windows from other colleges depicting a similar scene. In this way an impression can be given as to what the cathedral would have looked like with a complete scheme of painted windows. This thesis attempts to decipher the complex history of the cathedral's windows by integrating art and science in a multidisciplinary study.

This chapter starts by examining the current state of the windows in Christ Church, describing which windows are present, the dates of the windows as well as looking at the importance of some of the earlier glass which has been preserved in the cathedral. Interpretations of the 'older' (pre-Victorian) glass are given, relating to the movement and restoration of these windows from the 17th century onwards. The history of the cathedral is given, along with an introduction to the iconoclasm prevalent in the 17th century; also a section relating to Oxford during the Civil War describes why the cathedral was the target of the Puritans. After setting the scene of 17th century Oxford, the glass painters who worked in the city from the 1620s onwards are discussed, as well as some of their more prevalent works in the surrounding area.

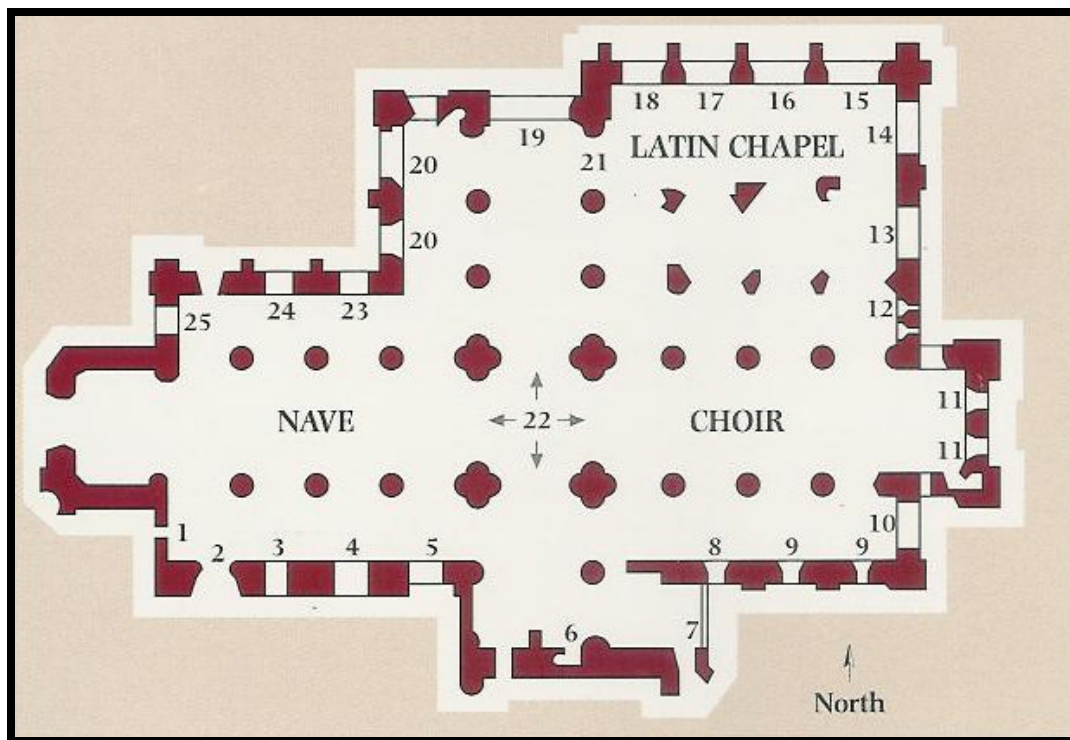
The reader is then introduced to the changing scheme of windows within the cathedral. This section reviews the available historical information and attempts to locate the different windows which would have been present in the building during three key periods: pre-1630, 1630-1660, and post-1660. An attempt is also made to reconstruct the 17th century Van Linge window scheme which would have been one of the largest window schemes in the country at the time (Power and Shortland 2007). An attempt is also made to describe what the cathedral may have looked like during this period, and also what feelings and emotions this may have evoked in the worshippers and visitors to the building. The results of analyses of the fragments of glass taken from the collection are presented, and interpretations are made about the windows based on this data.

3.1 Christ Church Cathedral Today

Christ Church is both the cathedral church of the diocese of Oxford, and the chapel of the college of Christ Church, one of the largest colleges of the University of Oxford. The cathedral is also one of the smallest in England. The cathedral building dates back to the 12th century, but the history of the site dates back earlier to the 8th

century. There have been various architectural alterations and additions between the 12th century and the present day which means that a variety of styles can be seen in the building.

Christ Church Cathedral today is filled with a large variety of stained and painted glass by various artists dating as far back as the early 14th century. The surviving windows are representational of a long and in some cases turbulent history of the building. The glass ranges from the 14th century windows located in the Latin Chapel and the Lucy Chapel, to the two surviving Van Linge windows, ‘Jonah before Nineveh’ and ‘Bishop King’, to the work of Burne-Jones and the work of Clayton and Bell. The most recent window added to the cathedral was by Clayton and Bell in 1891 and depicted the ‘Tree of Jesse’.



Number	Window	Artist	Date
1	Hope, Charity & Faith	Burne-Jones/Morris	1871
2	Crucifixion & 2 scenes from life of Christ	Wailes	1858
3	Life of St Peter	J.E. Rogers/Powell's	1864
4	Saul & David; The Virgin & St Joseph; Christ before High Priest; St Paul in prison; Betrayal of Christ; Paul & Luke	Clayton & Bell	1870
5	Samuel & Eli; Crossing the Red Sea; The vision of Isaiah; The wise & foolish virgins; Christ walking on the Sea of Galilee; The walk to Emmaus	Clayton & Bell	1872

6	Tree of Jesse	Clayton & Bell	1891
7	The Becket window		1320
8	Bishop Robert King	Abraham Van Linge	c.1630
9	Vision of Ezekiel & Vision of St John on Patmos	John Hardman Powell/Hardman	1870s
10	St Catherine	Burne-Jones/Morris	1878
11	Rose window & 2 lights – Christ’s passion	Clayton & Bell	1875
12	St Cecilia	Burne-Jones/Morris	1874
13	Vyner Memorial window	Burne-Jones/Morris	1872
14	St Frideswide window	Burne-Jones/Powell’s	1859
15	St Mary Magdalene; St John; St Frideswide	Clayton & Bell	1864
16	St Margaret; St Frideswide; St Catherine		c.1350
17	Gabriel; an archbishop; the Virgin		c.1350
18	St Catherine; Virgin & Child; St Hilda		c.1350
19	St Michael & angels fighting the Dragon	Clayton & Bell	1875
20	Fragments of painted window	Abraham Van Linge	c.1630
21	Fragments of former east window	William Price	1696
22	Windows made from former east window	Henri Gerente	1846
23	Abraham & Melchizedek; King David; Moses; Jesus & Nicodemus; Christ’s charge to Peter; Christ appearing to Thomas	Clayton & Bell	1873
24	Scenes from life of Stephen	Clayton & Bell	1874
25	Jonah surveying Nineveh	Abraham Van Linge	1631

Figure 3-1 Plan of Christ Church Today (Evans 1997: 13-14)

Figure 3-1 shows the cathedral as it is today, along with a table of the windows currently in the cathedral, the oldest is the glass in the tracery lights of the east window of the Lucy Chapel. This depicts, amongst other things, the martyrdom of Thomas à Becket, and this is dated to around 1320 (Opher 1994).

3.1.1 The Becket Window

The 14th century glass is found in the tracery lights of this window and shows images of Christ in Majesty, two censuring angels, the arms of France and England, some grotesque images, St. Augustine preaching, the murder of Becket, St. Martin dividing his cloak with a beggar, St. Blaise and St. Cuthbert holding the head of St. Oswald. The image of Becket is found in the centre of this window (Figure 3-2). The glass is strongly coloured using pot metal (where metal oxides were added to the glass to impart colours). The process of making this coloured glass was considered magic akin to

alchemy; and the light transmitted through the glass was thought to have supernatural properties (Opher 1994). Pot metal reds were particularly opaque and so a process known as flashing was developed, this is where layers of red glass were fused onto white glass, the more layers, the richer the colour (Opher 1994).



Figure 3-2 Image of Becket window

Sherwood and Pevsner (1975) claim the images are *in-situ* while many of the 19th century writers claim that they are not. A closer look at some of the detail of the

images in this window shows that the glass does not always fit exactly, suggesting that it may not have originally been designed for this space.

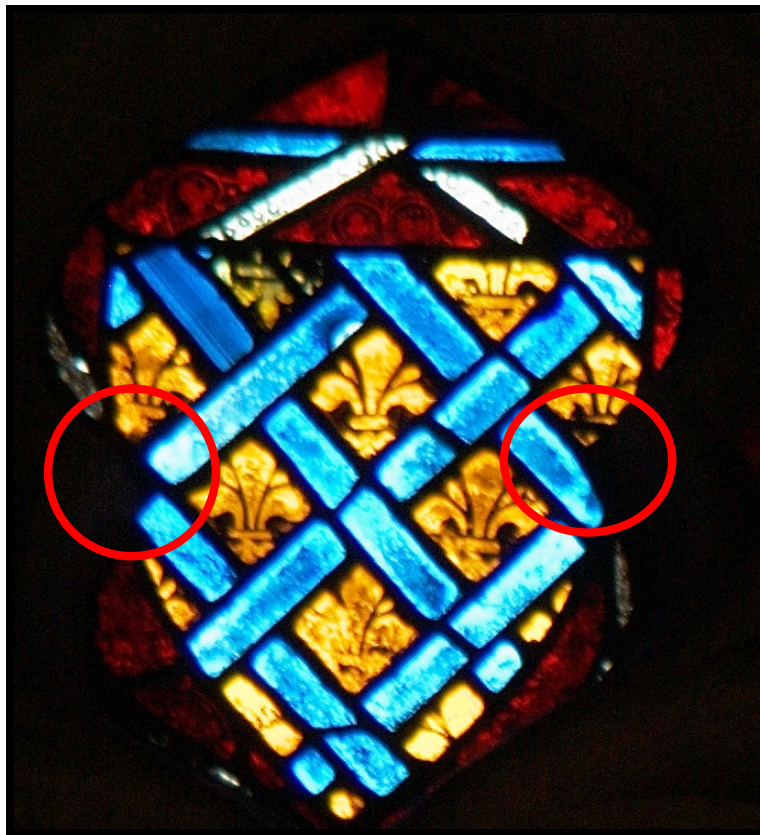


Figure 3-3 The arms of France and England (image courtesy of J. Rogers 2010)

In Figure 3-3 it can clearly be seen that the space filled with the arms of France is not the right size for the image. The left and right hand sides of the arms are cut by the window architecture. There are other examples of the images not quite fitting the spaces in which they are located throughout this window. For example in Figure 3-4 Christ appears to be missing the end of his left foot and in Figure 3-5 the window architecture appears to be cutting into the head of one of the knights. This all supports the descriptions of writers such as Winkles (1889), Trash (1849), King (1862), Parker et al (1858) and Thompson (1899) who all give alternative locations for different pieces of the glass from this window. Winkles (1889) in particular, says that Dean Liddell restored the 14th century glass to its original location within the building. Winston (1849) describes fragments of glass and then goes on to suggest where in the cathedral he thought they originated.

“It will be observed that there are five principal tracery lights in the window of the south transept already mentioned, which correspond in shape with these five

subjects. In the north window of the transept is also a representation of our Lord, seated, which clearly came from the topmost tracery light of the aforesaid south transept window, as well as many other tracery light subjects, removed from the same window. Amongst these I think may be reckoned the two shields in circles now in the head of the north transept window; one of which displays the arms of England, the other those of France” (Winston 1849: 15).

As both Figure 3-2 and Figure 3-3 clearly show, the arms of England and France are not in circles. It is probable that Dean Liddell either knew of the work of Winston, or was in contact with him and used his theories as to where these images should be located to ‘re-install’ the 14th century glass.

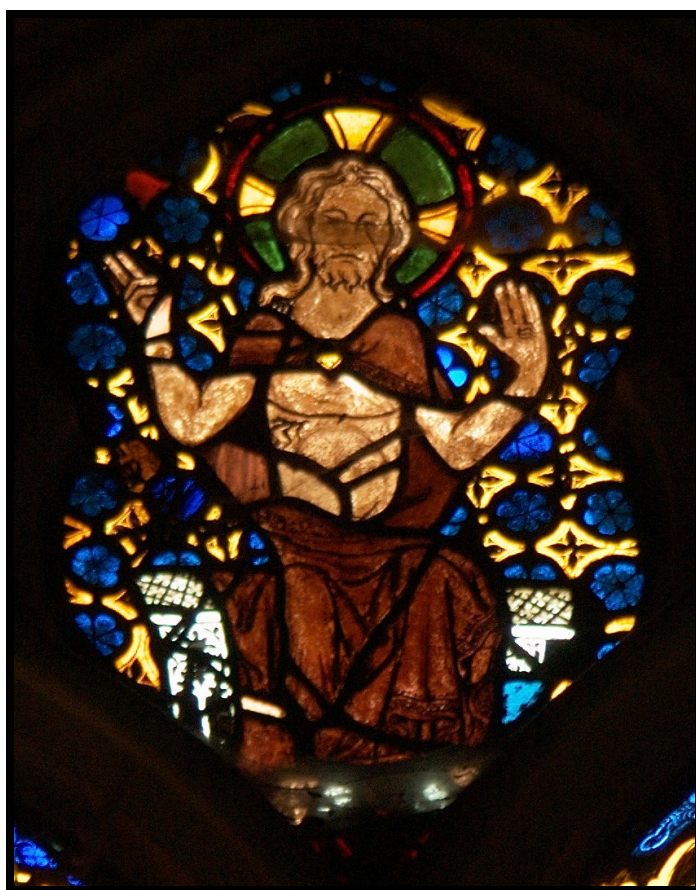


Figure 3-4 Christ in Majesty (image courtesy of J. Rogers 2010)



Figure 3-5 The murder of Becket (image courtesy of J. Rogers 2010)

3.1.2 The Latin Chapel Windows

Three windows in the Latin Chapel contain mid-14th century glass, these windows depict images of St. Catherine, the Virgin and Child, St. Hilda (Figure 3-6); Gabriel, an archbishop, the Virgin Annunciate; St. Margaret, St. Frideswide, and St. Catherine. Most of the figures hold a symbol to represent who they are, for example, St. Catherine is depicted with the wheel on which she was martyred. The images are surrounded by grisaille, this is a clear or grey glass with simple repeated designs, usually in the form of foliage, traced in black (Opher 1994). It has been suggested that the grisaille work which surrounds the 14th century images is not all original. Several areas are said to be later replacements or in some cases additions (Sherwood & Pevsner 1975). The Latin chapel windows employ a technique known as silver stain (Power 2007 pers. comm.). It is during the early part of the 14th century that silver stain begins to be used for church windows throughout northwest Europe. Silver stain was a convenient method for glass artists to achieve a permanent yellow colour by applying silver compounds mixed with a carrier medium such as ochre or clay onto the glass surface and then firing the glass at temperatures just below its softening range (Jembrih-

Simbürger et al. 2002). During the heating process the silver ions penetrate into the glass substrate and replace the alkali ions, the silver ions reduce to metallic silver; this then aggregates, forming metallic crystals. It is the size, shape and distribution of these nano-particles which determines the final colour on the glass (Jembrih-Simbürger et al 2002). This final colour can range from pale yellow, through bright yellow to dark brown (Jembrih-Simbürger et al 2002).

The figures are all depicted on coloured backgrounds and surrounded by ornate, gothic style architecture. The figures themselves are all stylised, they are tall and slender, and appear to be standing in a casual way. Winston (1847) describes glass from the period 1280-1380 as being of the 'Decorated' style. Windows of this style often had a figure under a canopy, and in a small window the figure would fill the whole of the lower lights (Winston 1847). The images which are present in the Latin Chapel windows do not currently fill the lower lights height wise, but they do appear to width wise.



Figure 3-6 A Latin Chapel window depicting St. Catherine, Virgin and Child, and St. Hilda (image courtesy J. Rogers 2010)

These three Latin Chapel windows are claimed by some writers to be *in-situ*, for example, Sherwood and Pevsner (1975). But as mentioned previously, Winkles (1889) claims that Dean Liddell restored much of the 14th century glass to its original locations, and other 19th century authors describe these windows as having various locations other than their current position. A closer inspection of these windows shows that they are neither *in-situ*, nor complete. For example, the images from the window depicted in Figure 3-6, showing St. Catherine, Virgin and Child, St. Hilda, appear to have truncated canopy architecture, and in the depictions of Sts. Margaret, Frideswide, and Catherine, and also the bishop (Figure 3-7), the canopy architecture appears to be made up of random architectural fragments fitted together.



Figure 3-7 An Archbishop in a window of the Latin Chapel

In terms of the window in Figure 3-8 depicting Gabriel, a bishop and the Virgin, the angel appears to be carrying part of a banner on which the word ‘Maria’ can be made out. The area beneath the images which, in most of the other windows contains the name of the person depicted is in all three cases blank. The angel and the virgin appear to be of a slightly different style to the rest of the images, for example, the coloured background is wider on these two than for the other figures and the surrounding architecture is neater and ‘cleaner’. This suggests that these two images are

not contemporary with the rest of the 14th century glass in the Latin Chapel. This is not to say that these images are modern, or even Victorian, but they may well be of a slightly earlier or later period.



Figure 3-8 Gabriel, Archbishop, Virgin Annunciate (image courtesy of J. Rogers 2010)

The window depicting Sts. Margaret, Frideswide, and Catherine (Figure 3-9) is interesting; the canopies are, as mentioned above, all formed from random fragments of architecture, pieced together into roughly the correct shape. If the name plates for these three images are correct, then we have three individuals from the legend of St. Frideswide. St. Frideswide prayed to both St. Catherine and St. Margaret during her life for help (Nash Ford 2000). St. Catherine is depicted as holding a sword and carrying the wheel on which she was martyred (Figure 3-10). St. Frideswide should be depicted with a pastoral staff, a fountain of water springing near her, and an ox at her feet (Dunbar 1904); in this window she has the pastoral staff and appears to be carrying something, possibly a book (Figure 3-10). St. Margaret should be represented with a dragon and sometimes carrying a banner (Dunbar 1905). In this window she has a cross atop a long staff and a creature at her feet, possibly with the head of a bear or lion; she is also carrying a feather (Figure 3-10).



Figure 3-9 Sts. Margaret, Frideswide, Catherine (image courtesy of J. Rogers 2010)



Figure 3-10 Sts. Margaret, Frideswide, Catherine in detail (image courtesy of J. Rogers 2010)

The identification of these women (certainly in the case of Frideswide and Margaret) is based on the name plate beneath the image. St. Catherine's name plate appears to be 'newer' than the others and has probably been restored or replaced at some point. St. Margaret and St. Frideswide's name plates are all made from sections of text, with the assumption being that these are as they were intended to be. The images of the saints are not shown with the artefacts traditionally associated with them, and the

other features of the windows have been altered. It is possible that the names have also been pieced together to represent the saints that it was assumed were in the window. Figure 3-11 shows the piecemeal way in which some of the names appear.



Figure 3-11 Name Plate of St. Margaret (image courtesy of J. Rogers 2010)

This hypothesis is supported if we take St. Margaret as a case study. A search of female saints who are associated with mythical beasts, crosses and crowns, returns St Martha. According to ‘The Golden Legend’ written in the 13th century, Martha, Mary and Lazarus were of royal descent and after baptism ended up in Marseilles. The legend says that there was, in a wood between Arles and Avignon, a great dragon with the head of a lion, the tail of a serpent and two wings on either side. Martha threw holy water on the beast and showed it the cross, which pacified the creature; she then bound it with her girdle so the people could kill it (The Golden Legend www.catholic-forum.com/saints/golden239.htm 2010). The image in the window is of a creature with the head of a lion, it has a tail, and the saint wears a crown, carries a cross and brandishes a feather. I propose, therefore, that this image is more likely to be that of St. Martha rather than St. Margaret. If this is St. Martha, then the image of the archbishop may well be an image of Lazarus who is often depicted with a bishop’s mitre and staff (Lanzi & Lanzi 2004). If this is the case, then the missing image would be that of Mary, the sister of Martha and Lazarus. It is possible that the St. Margaret name plate (Figure 3-11) is accurate and that there was at one point an image of St Margaret that has since been lost.

The name plate for St Frideswide ends in ‘da’, the name plate beneath the image quoted as St. Hilda only has the ‘da’ visible (Figure 3-12). St Hilda is the patron saint of Whitby and Stone Snakes (ammonites); she has no apparent connection with Oxford during the 14th century. The image, if the saint, is also very similar in style to that of St. Frideswide, therefore, I suggest that it is more likely to be a second depiction of St. Frideswide rather than St. Hilda. This hypothesis is supported by the fact that there appear to be two separate depictions of St. Catherine (Figure 3-6 and Figure 3-9).



Figure 3-12 Left: St. Frideswide Right: St Hilda? (images courtesy of J. Rogers 2010)

Some 19th century authors (Trash 1849; Parker et al 1858) mentioned that amongst the fragments of 14th century glass were also depictions of St Lucy and St Frideswide's parents, these are no longer present in the cathedral. If there were depictions of these three individuals along with a depiction of St Margaret, and a depiction of Mary, then this would be enough to fill the four windows of the Latin Chapel.

3.1.3 The 'Jonah' Window

There then follows several centuries break in evidence for glass at Christ Church. The next oldest window in the cathedral today is the 'Jonah before Nineveh' window (Figure 3-13), painted by Abraham van Linge in 1631, and originally commissioned by Charles Sunnibanke (Gutch 1786). The window depicts the prophet Jonah in the foreground of the painting beneath a gourd tree, with the city of Nineveh in the background. The city has been painted in a 'Dutch' style, and the Van Linges were known to have incorporated a certain amount of European and Dutch influence in their art (Parry 2006; Sherwood & Pevsner 1975). The window has had several locations

within the cathedral, as will be shown later, but, one thing is clear, the current location of the window was not where it was originally intended to reside.



Figure 3-13 'Jonah before Nineveh' (Image courtesy of J. Rogers 2010)

The window is entirely painted in enamels, with the exception of the figure of Jonah, which is mostly made of pot metal glass. The image shows part of the 'Jonah' story and this pictorial window is the last survivor of a huge glazing scheme that was undertaken in the 1630s (Power & Shortland 2007).

3.1.4 The 'Bishop King' Window

The second surviving 17th century window is the 'Bishop King' window (Figure 3-14), this is a painting of a single figure, it depicts the bishop (who was the first bishop of Oxford, and the last abbot of Osney Abbey) in his clerical robes wearing a mitre and holding a crook. The buildings depicted in the background appear quite 'Gothic' in nature, and behind them is rolling hills and countryside. It has been suggested that the buildings are representational of the remains of Osney Abbey. Above the bishop is depicted the arms of the King family, to the left of the bishop is the arms of the city of Oxford impaled with the arms of King, and on the right of the bishop is the arms of Osney impaled with the arms of King. Bishop King was the last abbot of Osney abbey and the first bishop of Oxford, but, according to Gutch (1786: 466) the arms of Osney were the arms of the City of Oxford until the translation of the cathedral from Osney to St. Frideswide's, then the city took St. Frideswide's arms. This window is unsigned and undated, but is still thought to be the work of the Van Linges (Sherwood & Pevsner 1975). One supporting factor for this idea is the reference by Gutch (1786) to all the windows of the south aisle bearing the arms of the King family. In particular, it has been suggested that this was the last window painted by Bernard Van Linge before he returned to the Continent (Dallaway 1806). Apart from the Gothic style of the abbey, the painting is in the style of the Van Linges work and it was commissioned by the King family at the time the Van Linges were undertaking the scheme in Christ Church.



Figure 3-14 The 'Bishop King' Window

3.1.5 Late and Post 17th Century Windows

Fragments of Van Linge work and late 17th century glass from the 'Price' window (1696), the 'Oliver' window (1700) along with the 'Gerenté' window (1854) can be seen in the clerestory lights of the north transept, and also in the lights of the tower (Figure 3-15 and Figure 3-16). A discussion of these artists and their work follows later in this chapter.



Figure 3-15 Fragments of Van Linge, Oliver, and Price windows in the north transept clerestory (image courtesy of J. Rogers 2010)



Figure 3-16 Fragments of the Gerenté window (image courtesy of J. Rogers 2010)

3.1.6 Mid-Late 19th Century Glass

The next surviving glass in the cathedral dates to the 19th century; this work is in a completely different style to the previous windows in the building, and constitutes the majority of the surviving stained glass. The earliest of this ‘new’ glass is a window by Wailes dating to 1858 depicting the Crucifixion along with two further scenes from the life of Christ (Evans 1997). The famous Burne-Jones window, designed by Burne-Jones, but made by Powell in 1859, it is at the east end of the Latin Chapel and depicts the story of St Frideswide in 16 separate scenes (Evans 1997). Of particular interest is the final scene which depicts the death of St Frideswide (Figure 3-17). The room the saint is in is very ‘modern’ for an 8th century saint, the window in the background of the room is made of ‘crown glass’, as is shown by the depiction of the ‘bull’s eyes’, there is a dresser containing a dining service, and in the right hand corner is what appears to be a flushing toilet!



Figure 3-17 A scene from the Burne-Jones window 1859 (image courtesy of J. Rogers 2010)

The work of Clayton and Bell can be seen throughout the cathedral, dating from 1864 through to 1891, this includes the ‘Tree of Jesse’ window and the main east end rose window and two lights (Evans 1997). A series of windows made by Morris but designed by Burne-Jones made between 1871 and 1878 also reside in the building (Evans 1997).

3.1.7 The Collection of Fragments

A vergier of the Cathedral, Matthew Power, happened to make a chance discovery in 2002. The vergier with the assistance of a college handyman was photographing the existing medieval windows. The handyman mentioned some old glass that he had been told to throw out but had not yet got around to. The vergier convinced the handyman to show him where this glass was, and eventually ended up crawling into a dark, dirty coal bunker located in Tom Quad, under the west end of the cathedral (Power & Shortland 2007). In the coal bunker was more than 9000 fragments of painted window glass, these appeared to be similar in style to the 17th century painted windows surviving in the Cathedral, 'Jonah before Nineveh' and 'Bishop King'. The fragments were therefore thought to be survivors of the 17th century (Power & Shortland 2007). As mentioned previously, the Van Linges had been commissioned to produce schemes of windows for some of the college chapels in Oxford, as well as individual windows for other buildings. It is believed that the majority of the fragments of glass uncovered in the coal bunker would have belonged to a scheme painted by the Van Linge brothers, prevalent in the cathedral during the 17th century (Power & Shortland 2007). The rest of the fragments are a mix of glass ranging from the medieval period through to the end of the Victorian period.

The fragments range in size from small undecorated colourless pieces, which are undated, to complete images of faces (Figure 3-18), architecture and heraldry. Of the latter pieces some have been assigned not only to a period of history i.e. 17th century, but also to a specific artist known to have worked on the windows, such as the Van Linges or Price.



Figure 3-18 Fragment depicting face painted by Van Linge from glass collection at Christ Church

As well as the fragments in the coal hole, a number of fragments can be found in the clerestory lights of the north transept of the cathedral. Again, these fragments are mostly the work of Van Linge and Price. It is believed that the painted fragments belong to windows by three artists, three of which were part of the Van Linge windows scheme. The Van Linge fragments in the collection and also in the clerestory represent 'the destruction of Sodom and Gomorrah', 'Christ's Entry to Jerusalem', and 'Christ Disputing with the Doctors', all dated to the 1630s and 1640s. Other windows represented in the fragments include 'the Nativity' by Price which was in the East window of the cathedral from 1696 until 1854 when it was replaced by the Gerenté window. Also from this period are thought to be fragments from the Oliver window which represented 'St Peter's release from Prison', dated 1700 (Figure 3-19). Although some fragments have provisionally been assigned to the latter window, it has not yet been conclusively proved to be the work of Oliver.



Figure 3-19 Potential fragments from the Oliver window 1700 in the collection

Amongst the clerestory windows and the tower windows can be seen remnants of the Gerenté window this window was removed from the east end of the cathedral in the 1870s, c.20 years after it was installed. The images from this window were originally placed in the clerestory lights, but later were again removed, broken up and placed in a decorative manner in the window of the cathedral tower (Power 2010 pers. comm.). Some fragments of Medieval and Victorian glass were also amongst the collection found in the coal hole. The combination of glass from different periods suggests that the fragments from the coal bunker were removed from the windows during 1870s renovations. What happened to the glass removed during earlier periods is unknown, it is possible that this too has survived albeit in fragmentary form and is lying somewhere undiscovered in the cathedral grounds. What is more likely is that any earlier glass has been lost. Examples of 15th and 16th century glass can be found in the windows of the Chapter House. One of the few records relating to the windows dated 2nd June 1651 ordered that all pictures representing god, good or bad angels or saints should be removed from the windows of the cathedral and used to repair the windows in other parts of the college. Part of the iconoclastic zeal was an objection to religious images used in ecclesiastical settings, this coupled with expense involved in changing

the windows suggests that it is highly likely that earlier glass would have been preserved in other areas of the college. The same sentiment of using older glass to replace broken glass may still have been prevalent in the 1870s and this may explain why when the cathedral was renovated the windows that were removed were retained. Although this explains the survival of the glass it does not explain how the fragments came to be in a coal bunker.

3.2 History of Christ Church Cathedral

The history of the cathedral begins around the 8th century, when a monastery was founded by or for St Frideswide (RCHME 1939). Little is known for certain about St. Frideswide, except that she was abbess of a well-endowed nunnery in Oxford during the Anglo-Saxon period, and that she was commemorated at the later monastery as a saint at the beginning of the 11th century (Reames 2003). The legend of St Frideswide says that she was the daughter of King Didan of Lower Mercia and born in Oxford during the mid 7th century, and brought up at Didcot (Nash Ford 2000). After the death of her mother, Frideswide returned to Oxford and asked her father for land near the gates of the city, where she could build a church. Didan subsequently built a convent for Frideswide and her companions adjoining the church (Nash Ford 2000). Prince Aelfgar, Earl of Leicester asked Frideswide to marry him, and when she refused he decided to take her by force (Nash Ford 2000). Frideswide and two of her companions fled down the river Thames to Abingdon where they sought refuge in the forest; at Betona, Frideswide transformed a pig-sty into a small oratory, she prayed for water and a well appeared and it was here, where she and her companions lived for c.3 years (Nash Ford 2000). Prince Aelfgar meanwhile decided to march on Oxford, and threatened to burn the city down if Frideswide was not delivered to him. Didan refused to sacrifice his daughter, but the people of Oxford opened the gates to him and told him where Frideswide was hiding. Frideswide received the messengers sent by Aelfgar, but her answer remained unchanged (Nash Ford 2000). In some versions of the story, it is at this point that Aelfgar rides to Frideswide in the forest where she prays to Sts. Catherine and Cecilia for assistance and the prince is struck blind. After pleading to have his sight restored, Frideswide bathes his eyes in water from the well and prays and his sight is restored, she then returns to Oxford, curing a leper on the way, and after many happy

years in Oxford, she retires to Binsey where she builds a small chapel and again prays for water and a spring appears (Nash Ford 2000). Frideswide died on the 19th October 735 and was buried at the nunnery in Oxford. Many pilgrims came to visit her grave and many miracles occurred and she was soon after proclaimed a saint (Nash Ford 2001).

Although the above story is a legend, there are some elements of truth to the tale, for example, Didan appears to have been a real man and ruled the Upper Thames Valley, probably as a sub-king to King Wulfhere of Mercia; likewise Aelfgar may also have been a sub-king (Nash Ford 2001). The first written version of the story is by William of Malmesbury in c.1125 (Reames 2003).

The nunnery was burned by the Danes around 1002 and restored as a monastery under Ethelred II (the Unready) (RCHME 1939). It has been suggested that the nuns had either already been displaced by this date or were displaced by the Danes and the fire itself (Reames 2003). When the monastery was rebuilt by Ethelred, it was established for secular canons and endowed with land (Page 1907), these clerics were not subject to any monastic rule and they themselves were also permitted to hold property (Reames 2003). By the time of the Conquest the monastery had become a 'minster', which it remained until the 12th century when it became a priory to which Henry I granted a charter in 1122 (RCHME 1939). The priory was of Austin Canons, who followed the rule of St. Augustine (Reames 2003). The priory obtained most of its endowments from the residents of Oxford (Page 1907), and between 1122 and 1180, the canons excavated the grave of St. Frideswide, rediscovered her relics and revived her 'cult' following (Reames 2003). In 1180, the relics of St. Frideswide were translated to a new shrine within the church, and over 100 miracles are said to have occurred after the translation (Reames 2003). The 3rd prior, Prior Philip, left an account of the translation of the saint's bones, which occurred on the 12th February 1180 in the presence of the Archbishop of Canterbury, Alexius, the Pope's legate, and the Bishops of Winchester, Ely, Norwich, St. David's and the elect of St. Andrew (Page 1907).

Virtually nothing remains of this early phase of the cathedral's history, except possibly for some old tombs located in the south transept (RCHME 1939), but these are undated and Wood wrote that all of the early tomb slabs were removed during the 1660s (Wood quoted in Gutch 1786). The building was rebuilt during the late 12th and early 13th centuries (Sherwood & Pevsner 1975), and it is this which formed the basis of the

current cathedral. The late 12th century church consisted of a nave with a north and south aisle, north and south transepts both with west and east aisles and a choir with north and south aisles (RCHME 1939). Figure 3-20 shows a plan of the 12th century cathedral, the dotted lines indicate where the original outer walls of the building would have been. The west end of the building original extended to the left, but the exact distance is unknown (RCHME 1939).

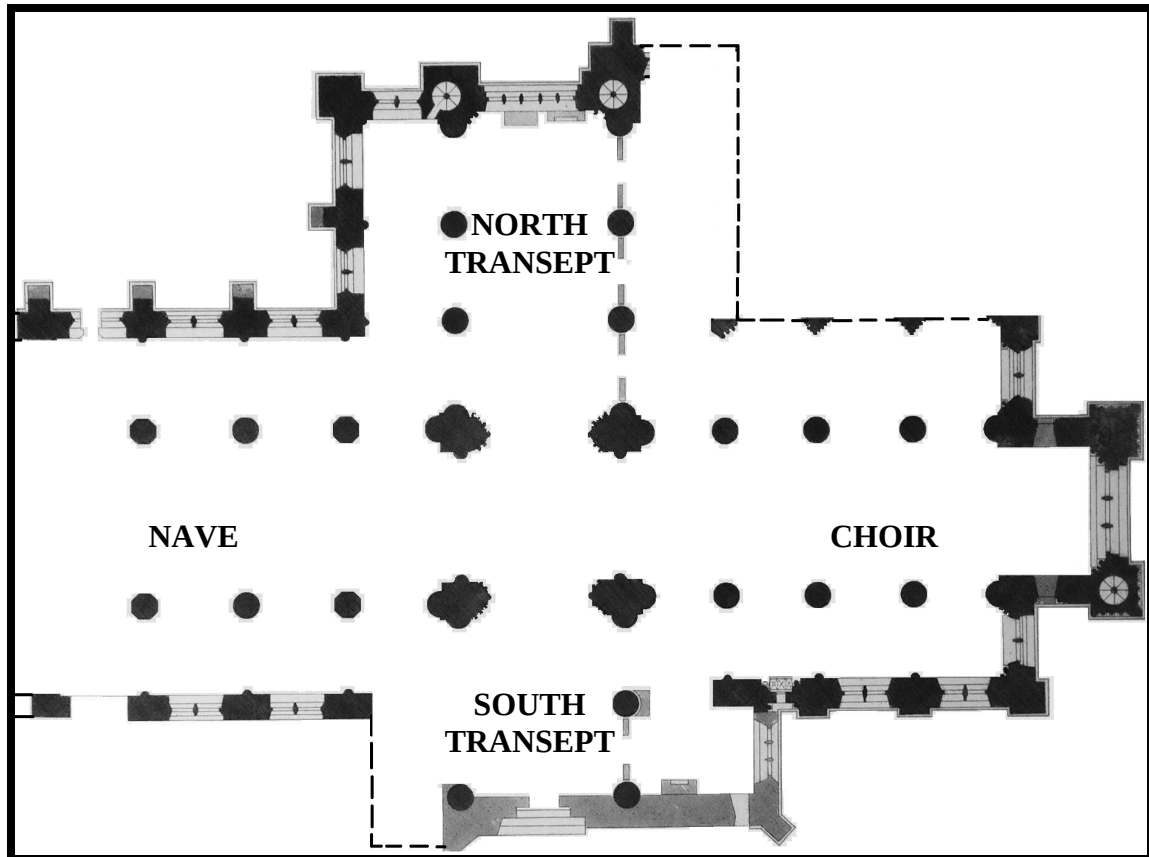


Figure 3-20 12th century Plan of Christ Church

During the 13th century, the Lady Chapel was built by piercing arches through the walls of the 12th century building. It was after these alterations when a second translation of the body of St. Frideswide took place in 1289 (RCHME 1939). Figure 3-21 shows the plan of the 13th century cathedral with the addition of the Lady Chapel, again the suggested lines of the outer walls are depicted by dotted lines.

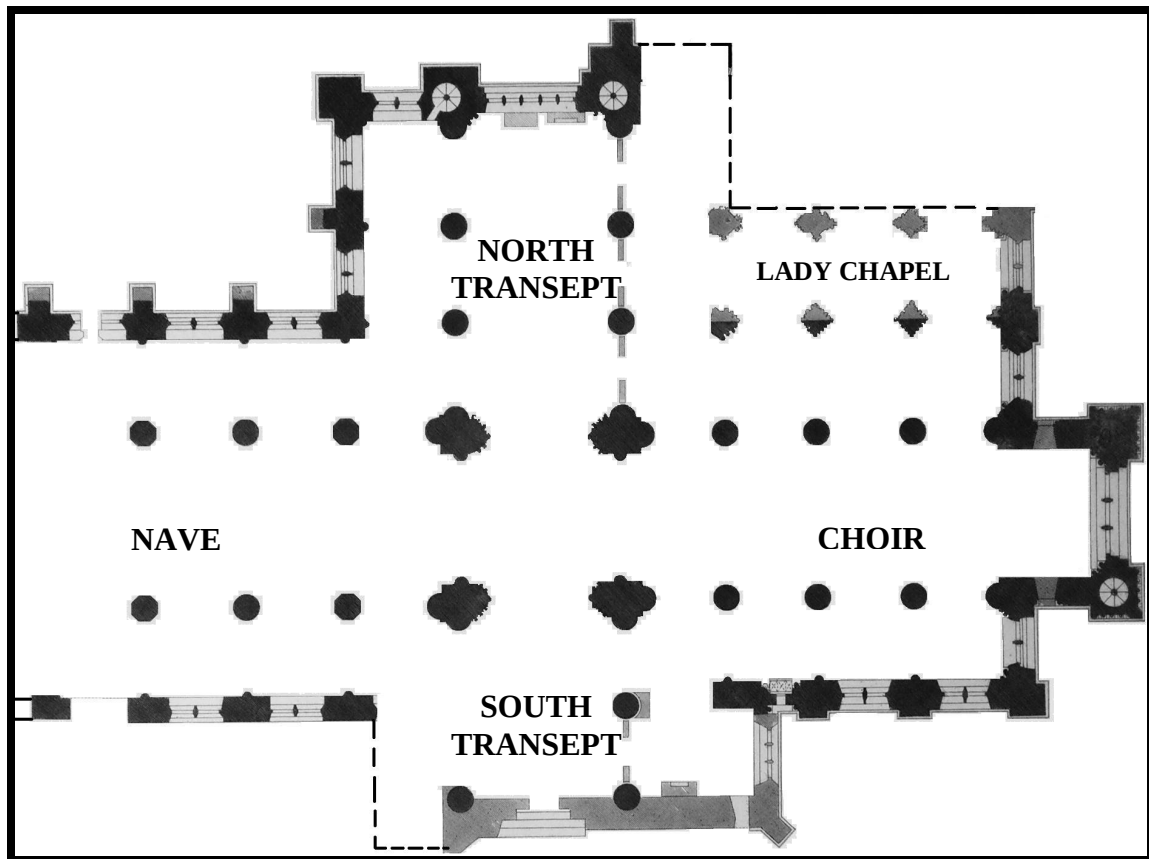


Figure 3-21 13th century Plan of Christ Church

The Latin chapel was built in the early 14th century and the chapel of St Lucy (located in the south transept) had its east end remodelled (RCHME 1939) into what can be seen today. In 1330 the debts of the priory amounted to at least £400 (Page 1907). By 1368, the King took the priory lands into his own hands because of the large debts and granted custody to two of his servants in order to pay some of the debts. By January 1423, the bishop issued injunctions that the excessive and ‘voluptuous’ expenses that had impoverished the house were to be discontinued (Page 1907). Figure 3-22 shows a plan of the 14th century cathedral, this is very similar to the plan of today with the exception of the west end of the building, which still extended further to the west.

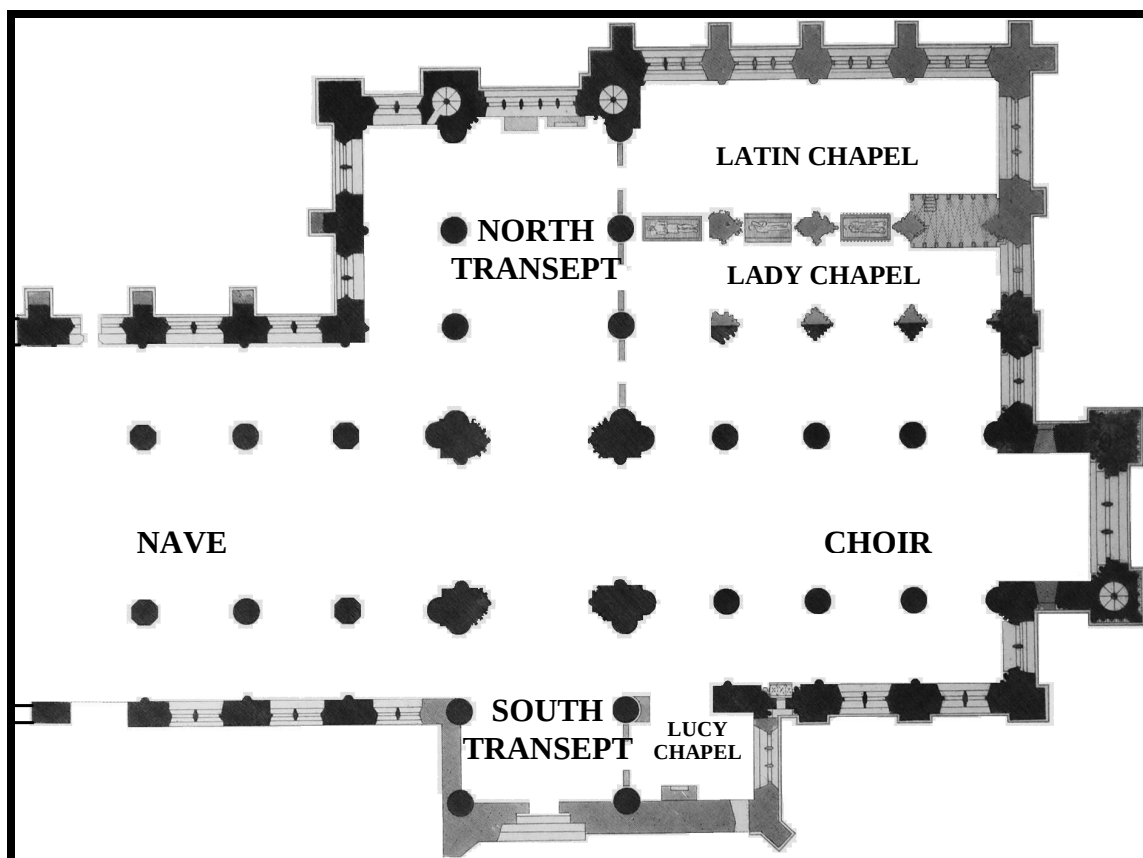


Figure 3-22 14th century plan of Christ Church

3.2.1 Wolsey

In 1525, Cardinal Wolsey established his Cardinal College on the site, in order to do this he suppressed the priory of St Frideswide; originally he intended to build a separate chapel for the college but in the end used the church of St Frideswide as the college chapel (Sherwood & Pevsner 1975). In order to accommodate the design of Wolsey's new college, the west end of the cathedral had to be demolished (RCHME 1939). All authors agree that Wolsey reduced the size of the nave, but the extent to which this is the case has been debated. It is generally accepted that the plan of the cathedral as it is today is largely the result of Wolsey's work, the later changes to the exterior of the building being the shapes and design of the windows. In particular, when Wolsey demolished and rebuilt the west end of the cathedral he had a large window inserted in the upper part (RCHME 1939).

It was not until 1546 that Henry VIII officially made Christ Church a cathedral; although Oxford had been made a bishopric in 1542, the cathedral was

originally intended to be at Osney Abbey (Sherwood & Pevsner 1975). Henry changed his mind and the chapel of Wolsey's Cardinal College became Christ Church, both the college chapel and the diocesan cathedral.

3.2.2 Laudian Reforms

The next major changes in the cathedral occurred during the 1630s, they were organised by the Dean of Christ Church, Brian Duppa. These changes included new panelling and woodwork, new screens in the nave, and a marble floor. None of these have survived (Power & Shortland 2007). Duppa also ordered the windows of the nave aisles and the transepts to be altered from three lights to two lights, and the window of the east end of the cathedral to be altered from five lights to three lights (Winkles 1889). In order to do this, several of the medieval windows had to be removed, and new painted glass was inserted in their place. Wood tells us that *"they took down all the old windows (except four in the Divinity Chapel) which were set up anciently by the canons of St. Frideswyde's Priory...Which being done, and the fine Architecture or Crustation of those windows cut and sawn away, they put up new painted windows with several scripture stories in them, admirably well performed by the exquisite hand of Abraham Van Ling, a Dutchman, an. 1634"* (Wood quoted in Gutch 1786: 462). During the Civil War these windows were seen by some to be papist and idolatrous and were removed between 1648 and 1651, and at a later date, probably around 1660, the surviving windows were replaced in the building (Urban 1850). In the 1640s Oxford was in the hands of the Royalists, but, when Charles I was defeated, the Parliamentarians took over the city. In 1646, Parliament sent Puritan preachers to Oxford, and in 1647, Parliament sent inspectors to carry out an inquiry into the state of the colleges. In 1648, the dean and seven canons of Christ Church were ejected and replaced by men acceptable to parliament (Horn 1996). These men shared the Puritan views of Parliament and their instalment would explain why it was during the period 1648 to 1660 that the painted windows were removed.

3.2.3 19th Century Changes

Over the course of the next 200 years, the painted windows of the cathedral appear to be moved to various parts of the building, but the next substantial changes to building occur during the 1850s. Dean Liddell rearranged the interior of the cathedral as he felt that the building was not living up to its potential as a cathedral. The first amendments were only ever intended to be temporary, and were therefore inexpensive and hastily completed. It was not until the 1870s that Dean Liddell's vision for the cathedral was completed at a cost of more than £17,000 (Thompson 1899). Most of the renovations involved removing the work of the 1630s, such as changing the Duppa two light windows back to the original three light style (Winkles 1889). The other major architectural change attributed to Dean Liddell is the addition of a bay at the west end of the nave replacing one of the ones destroyed by Wolsey and the subsequent removal of the west window (Thompson 1899). It is this west end 'extension' that has been made into the main entrance of the cathedral. The architecture of the cathedral has changed very little since this time. Figure 3-23 shows the plan of the cathedral as it is today.

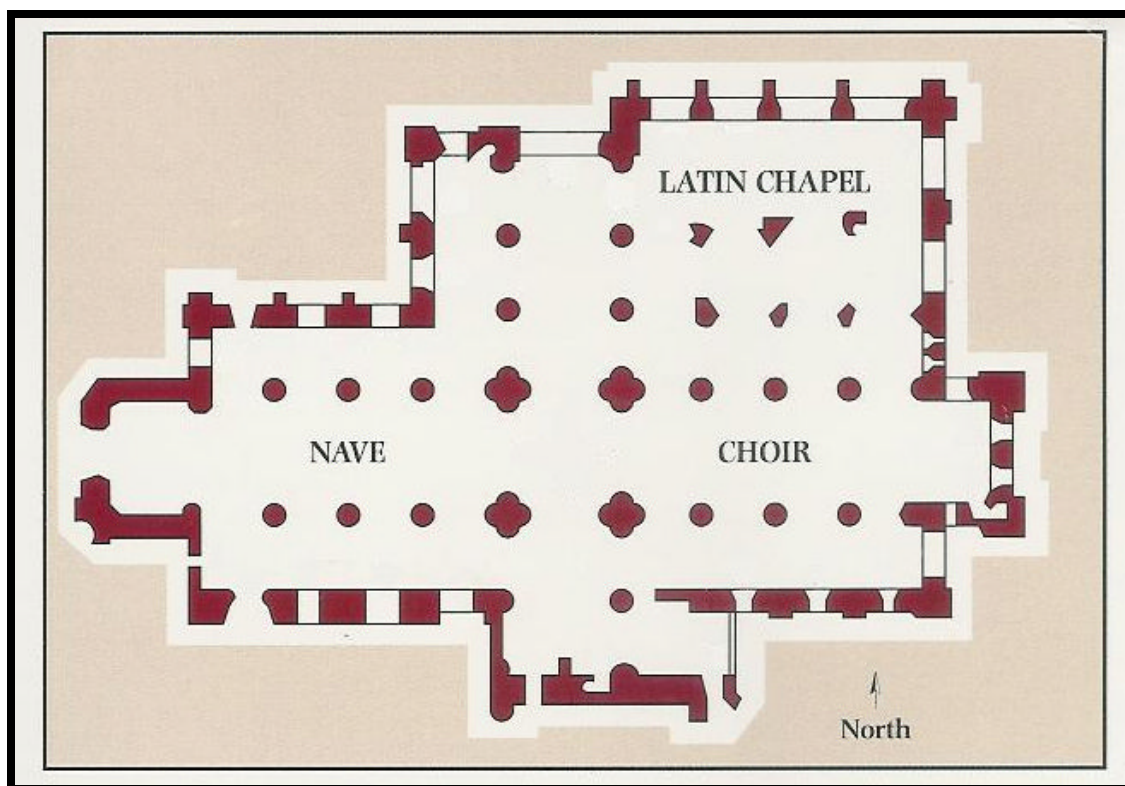


Figure 3-23 Plan of Christ Church Today

3.3 17th Century Windows: the Van Linge Scheme

This thesis focuses on the windows of the cathedral and in particular those of the 17th century. Since the Reformation in the 16th century official ‘image-breaking’ had been used to establish religious change (Spraggon 2003). The idea was that images and monuments were akin to idols and therefore their presence in churches signified idolatry. As far as the Puritans were concerned the use of idols were forbidden by God himself, in the 10 Commandments it states “*Do not make for yourselves images of anything in heaven or on earth or in the water under the earth. Do not bow down to any idol or worship it, because I am the Lord your God and I tolerate no rivals. I bring punishment on those who hate me and on their descendants down to the third and fourth generation*” (Exodus 20: 4-5). Therefore painted windows depicting Bible stories were seen by some as ‘idolising’ the word of God. Images of saints and martyrs were also closely associated with the Roman Catholics, and it was felt that in order to fully establish the Protestant church, these items had to be removed from churches. This led to widespread iconoclasm throughout the country; “*imagery was a tool of the devil who seduced men through appeals to the senses*” (Spraggon 2003: 3). At the start of the reign of Elizabeth I (1558) the emphasis was on the destruction of images rather than the removal, and this was both a religious and a political move to establish the authority of the Protestant Church in England. The whole need to firmly establish the Protestant church was fuelled by the need to protect the realm from the feared and mistrusted Catholic powers, the Pope, and those rulers deemed to be his agents (Collinson 2009). But, by 1560 even Elizabeth had become uncomfortable with the level of iconoclasm and she made a proclamation which prohibited the destruction of church monuments including windows (Spraggon 2003). The main argument against the use of images was that they encouraged idolatry and all things false; they were often described as the ‘teachers of lies’ (Spraggon 2003). Yet, this objection was not against art itself, just the use of religious themes within ecclesiastical settings. Painted and stained glass windows, although frowned upon were often thought not as dangerous as some of the other monuments or religious artefacts, for example, many survived Queen Elizabeth’s Ordinance for their destruction. One possible reason for this would have been the cost of replacing the glass, as William Harrison in 1577 wrote “*As for churches themselves, belles and times of morning and evening praier remain as in time past, saving that all*

images, shrines, tabernacles, rood lofetes and monuments of idolatrie are removed, taken down and defaced: Onlie the stories in glasse windowes excepted, which, for want of sufficient store of new stuffe, and by reason of extreame charge that should grow by the alteration of the same into white panes throughout the realme, are not altogether abolished in most places at once, but by little and little suffered to decaie that white glass may be set up in their roomes” (Eden 1913: 24).

By the early 17th century there was an increasing support within the established church which advocated a more tolerant attitude towards the use of images within ecclesiastical buildings (Spraggon 2003). This growing idea, which was adopted by Archbishop Laud and many of his following, promoted the ‘beauty of holiness’ (Spraggon 2003), and encouraged the refurbishment and restoration of churches. Laud and his colleagues were largely responsible for the visual transformation which many churches and chapels underwent during the 1620s and 1630s (Parry 2006). These men saw painted glass as an aid to devotion, as a way of teaching the scripture to the illiterate. At the same time the Puritans leapt on this thinking as returning to the old catholic ways, a return of ‘popery and superstition’ (Parry 2006). In 1629 Charles I made a proclamation preventing the decay of churches and chapels. It was also around this time that many educated men began to express their religious views through literature and poetry. There are several examples of poetry from the 17th century which defend painted and stained glass windows, they also often represent the Puritans in a particularly bad light (Smyth 2006), but there are also examples of pro-Puritan poetry condemning the use of imagery (Smyth 2006). Laud’s initial attempts at slowing Puritanism were successful, but the more zealous Laud and his followers became in terms of ‘beautifying’ churches and promoting high church values, the fiercer was the opposition against him (Norton 1864). Reformers came to the conclusion that the church was once again aligning itself with Rome, and the only way to prevent this would be to extirpate the idolatrous views, the enemy was now within the church (Spraggon 2003). When the Long Parliament met in 1640, this signified the beginning of the end for Laud, and with it came a new zealous interest in religious iconoclasm. Parliament itself became the driving force behind the destruction encouraging the army to remove or destroy religious iconography wherever they went. There are records of iconoclastic riots occurring throughout the country, mostly at the hands of conscripted

soldiers but often with the collusion of the local populace, although these records are scarce (Spraggon 2003). The outbreak of the Civil War really highlighted the divide in religious as well as political values, many of the high church and Laudian supporters were Royalists. Most of the iconoclastic zeal only lasted during the early 1640s, although the Puritanic ideal lasted until the restoration of the monarchy in 1660. During the 1650s the reformation of images was less of an issue, many felt that a satisfactory purge had occurred during the preceding decade. This is not to say the iconoclastic attacks ceased, but they eased (Spraggon 2003).

3.4 Oxford during the Civil War

Charles I stayed at Christ Church several times, the first was in 1625, when he adjourned parliament to Oxford, because plague had infected Westminster (Crossley & Elrington 1979), but, it was during the Civil War that Charles made Oxford his headquarters and he himself resided in Christ Church (Horn 1996). The town and university had a somewhat turbulent relationship, but the onset of the war saw both 'town and gown' working together; and by 1642 both the city and the university were armed (Crossley & Elrington 1979), and fortification of the city began (Salter & Lobel 1954). In September 1642, Parliamentary forces entered Oxford, they demolished the Royalist fortifications, disarmed university men and searched houses (Crossley & Elrington 1979), but left the city a month later. In October 1642, Charles I was welcomed into the city, and Oxford remained the Royalist headquarters from 1642 until 1646 (Salter & Lobel 1954). In this period, Oxford housed the king and his court, the central law courts, the exchequer and had a mint. While some of the judges and court officials moved to Oxford others remained in London, those who remained were believed to have forfeited their places and were replaced. In 1643, Charles issued a proclamation inviting members of Parliament to Oxford, declaring the Westminster Parliament guilty of high treason. Parliament issued several orders forbidding the courts to move, and by 1644, Parliament decided that any court official who did move to Oxford had forfeited their position and were to be replaced. This led to two sets of courts being in session during 1644 and 1645, one in London and one in Oxford (Crossley & Elrington 1979).

During 1644, Parliamentary troops laid siege to Oxford in an attempt to trap the king, but the army abandoned the siege when the king escaped. In 1645, Sir Thomas Fairfax took command of the Parliamentary forces surrounding the city and began building siege-works to the east of the River Cherwell. The Royalists in the city countered the siege by flooding the meadows around the Cherwell and burning the houses in the suburbs of Oxford. The Royalists also pulled down all the houses within three miles of Oxford to prevent the Parliamentary army finding resources (Crossley & Elrington 1979).

Archbishop Laud, who had promoted the idea of 'beautifying' ecclesiastical buildings, had become involved with political issues by encouraging the people to support the monarchy. Not only was Laud accused of being a Romaniser, but he was also a Monarchist, and he was accused of turning the king against all parliaments (Norton 1864). Laud's influence in the university contributed to the troubles between the town and the university, and he was not a popular man in Oxford, and in 1645 Laud was executed (Salter & Lobel 1954).

The next siege of Oxford began in 1646, the king fled the city in disguise and the Parliamentary General Fairfax was ordered not to allow anyone out of the city except to negotiate terms of surrender. On the 24th June 1646, the main body of the Royalist army surrendered and on the 25th June, the keys to the city were handed to Fairfax (Crossley & Elrington 1979). From this time Oxford became a Parliamentary city, although over the next few years Royalist attempts to retake the city were made. After the city was taken, a visitation of the University was ordered for the reformation of the University and several of the colleges and halls (Salter & Lobel 1954).

3.5 The Glass Painters

The majority of the 17th century painted glass at Christ Church was created by the Van Linges. Bernard and Abraham Van Linge are believed to be brothers from Emden, although some authors have suggested that they were father and son (Dallaway 1806). Very little is known about their background and connections prior to coming to England (Urban 1850). Bernard was certainly the elder of the two, and is thought to have come to England first, around 1621, he is believed to have at some point returned to Emden, but the date that this occurred is debated. Abraham followed Bernard to

England, but the date he arrived is uncertain, some authors claim he obtained English citizenship and remained until his death (Archer 1975), while others claim he returned to the continent around the outbreak of the Civil War (Eden 1913).

Archbishops Abbot and Laud both encouraged the revival of glass painting in churches by patronising Flemish artisans “*the best known of them were Baptista Sutton and the two Van Linges, Bernard and Abraham, many specimens of whose work, signed and dated, may be seen today – especially in Oxford Colleges*” (Eden 1913: 120). The architecture and landscapes depicted in their work is very reminiscent of 16th and 17th century Netherlands (Sherwood & Pevsner 1975). It has been suggested that many of their windows were taken from designs on prints and paintings of the Low Countries (Parry 2006). Bernard is often said to have been the father of glass-painting in England in its ‘modern’ form, and the continuance of the art is attributed to the younger Van Linge, Abraham (“J.S.” 1807). “J.S.” goes on to explain that after the Van Linges departed, the art of glass-painting fell into a poor state, although, some authors believe that artists from either the same school as the Van Linges, or who were taught by the Van Linges, did continue to work (Walpole et al. 1828). It has been suggested that the Van Linges may have had a workshop in Southwark (Parry 2006), and this may also have been where their ‘school’ was located.

The Van Linges were glass painters, they painted with enamels onto white glass (in terms of stained glass, the term white glass is often used, this refers to colourless glass). The enamels were made by mixing a highly fusible lead glass with various metallic oxides to provide the required colour; this highly fusible coloured glass was then ground to a fine powder, which when mixed with a suitable medium could be applied to the pane of glass as a paint (Lowe 1975). When the sheet of painted glass was then fired, the enamel regained its transparency, and became a thin coat of transparent coloured glass on the surface of the window (Lowe 1975). In this way the whole of a window could be treated like a giant canvas. One picture would extend over several lights of a window (Eden 1913). There are several examples of the work of the Van Linges in many of the Oxford colleges as well as in Christ Church cathedral. For example, University, Queen’s, Lincoln, Balliol and Wadham College chapels all feature the work of the Van Linge brothers (Black 1977). The work in Wadham College chapel is by Bernard Van Linge, and it was the first Van Linge commission in Oxford (Urban

1850). The windows on the north and south sides of the chapel all depict either saints or prophets (Figure 3-24), while the east window depicts types and anti-types of the Bible (Figure 3-25). While the east window is definitely the work of Bernard Van Linge and dated 1622, it has been argued that some of the windows are earlier in date c.1616 and were restored by Van Linge, this is thought to be the case based on the style of the figures (Power 2009: pers. comm.).



Figure 3-24 Prophets from Wadham College, most likely restored by Bernard Van Linge.



Figure 3-25 The east window of Wadham College chapel painted by Van Linge 1622.

Lincoln College chapel displays the early work of Abraham Van Linge and is dated to between 1629 and 1631 (Sherwood & Pevsner 1975). Again, the windows in the chapel porch display various saints and ‘Jonah and the Whale’, and the east window depicts biblical types and anti-types (Figure 3-26).



Figure 3-26 The east window of Lincoln College chapel.

The windows of Queen's College chapel are all Van Linge windows and they are almost all pictorial, depicting scenes and passages from the Bible. There are two windows near the entrance to the building which depict individuals, again in the form of saints. It is interesting to note that the scenes depicted in these windows do not appear

to be in any specific order. For example, on the south side of the chapel from west to east are depicted Pentecost, the Nativity, the empty tomb, and the visitation to the shepherds. The east window is another Nativity scene, this time with very obvious restoration work. The north side of the chapel, again from west to east is depicted the Annunciation and Mary and Joseph being turned away from the Inn, The Last Supper and the Crucifixion, and two windows depicting the Last Judgement. The Annunciation window and the Last Supper window are interesting because they both contain two parts of the story, an internal scene and an external scene (Figure 3-27). There are two possible reasons for the apparent lack of order or sequence to the windows, a) the windows were commissioned but not installed until a later date, and the artists were not involved in the installation of the scheme (the chapel website says that the fabric of the chapel is virtually unchanged from when it was consecrated by the Archbishop of York 1719). The latest Van Linge work recorded in Oxford was the cathedral windows dating at latest to the 1640s, therefore, the Queen's College windows would have been no later than the 1640s in date. Or b) the windows were painted and installed and then when the rest of the college was remodelled in the 18th century, the windows were removed for their protection and then re-installed, prior to the consecration in 1719.



Figure 3-27 The Last Supper and Crucifixion by Van Linge in Queen's College chapel

Balliol College chapel was refurbished in the 17th century and it was during this time that the existing windows in the chapel were repaired and two new ones by Abraham Van Linge were inserted, these depicted 'Philip and the Eunuch' and 'the illness of Hezekiah' and were donated by Richard Atkyns and Peter Wentworth in 1637 (Salter & Lobel 1954). Certainly when this volume of the VCH was published in 1954,

both of the Van Linge windows survived, but both had been broken down into two further windows.

The last Oxford chapel to have Van Linge windows is University College chapel. The windows in this chapel were painted by Abraham Van Linge in the 1640s and again, are all pictorial windows of biblical scenes. The windows of this chapel were placed into storage when the windows of Christ Church were destroyed by the puritans. The windows were then installed into the chapel during the 1660s (Black 1977). For this reason, the original intended order of the scheme is unknown. Also, the Van Linge windows are on the north and south side of the chapel. The windows in this chapel depict on the south side of the porch, 'Christ overturning the Temple', and on the south side of the main body of the chapel, from west to east, 'Mary and Martha', 'Abraham and Isaac', 'Adam and Eve after the expulsion', and 'Adam and Eve in Eden'. While, on the north side, is depicted (west to east) 'Jacob's Ladder' (Figure 3-28), 'Elijah and Elisha', and 'Jonah and the Whale'.



Figure 3-28 'Jacob's Ladder' from University College Chapel

College Chapel	Windows	Date
Wadham	North and South sides of church – Saints and Prophets – restoration Bernard Van Linge	1616 – 1622
Wadham	East window – biblical type and anti-types – Bernard Van Linge	1622
Lincoln	Porch – Saints and Jonah – Abraham Van Linge	1629-1631

Lincoln	East window – biblical types and anti-types – Abraham Van Linge	1629-1631
Queen's	All windows – Abraham Van Linge	
Balliol	'Philip and the Eunuch' 'The illness of Hezekiah' Abraham Van Linge	1637
University	North and South sides of nave and South side of porch – Abraham Van Linge	1640s

Table 3-1 Table of College Chapels and their Van Linge windows

The work of the Van Linges is known throughout many of the Oxford colleges, mostly in the college chapels (Table 3-1), but some 'secular' work in the form of portraits on glass have been found in some of the college halls and libraries (Lane Poole 1929). Most of the Van Linge works are found in centres of culture, such as Oxford and London, but a few examples can also be found in private chapels and houses (Rackham 1942). For example, Lydiard House in Swindon. Lydiard was the home of the St John family; the house contains a painted window in the 'Dressing Room' (Figure 3-29) and is dated to 1630. The window is made up of individual quarries and each one is hand painted. The quarries depict mermaids, centaurs, satyrs, humans hunting and sailing, exotic fruit and flowers, and wild and domestic animals. The window is believed to have been painted by Abraham Van Linge (Cummings 2009).



Figure 3-29 Van Linge window from Lydiard House, Swindon

St Mary's Church at Lydiard Tregoz, Swindon also has claims to a Van Linge window (Figure 3-30). The east window of the church which depicts an olive tree flanked by St John the Baptist and St. John the Evangelist. Below the tree, in the background to the window, is seen, on one side, a man and his dog while on the other can be seen a sailing boat on the river (Archer 1975). Although the window in the church is unsigned, it is believed to be by the same artist as the window in the house, this is because the boat on the river is very similar in style to the boats in the Lydiard House window.



Figure 3-30 Van Linge window from St Mary's Church, Lydiard Tregoze, Swindon (image courtesy of J. Rogers)

The Lydiard windows are thought to represent some of the early work of Abraham Van Linge. *“Certain early idioms, however, were carried over into his later*

work. *The Jonah windows at University College and at Christ Church both have ships comparable with those at Lydiard and the leaves of the Tree of Life in The Temptation scene at University College closely resemble those on the Lydiard St John olive tree*" (Archer 1975: 31).

The private chapel of Wroxton Abbey, Oxfordshire, also contains a Van Linge window. This window is described as ill-assorted and patchwork in nature, although the actual Van Linge work can still be identified (Kirby 1965). The window is originally dated 1632 (Kirby 1965); although, if this window is fragmentary, the earlier heraldry may not be the work of Van Linge. Almost all of the glass in the window was enamelled, and it is unknown whether Van Linge was commissioned to fill a window utilising the earlier fragments, or whether Van Linge had a separate window and over the course of time both windows have been destroyed, and another artist has placed them all in the same window. In terms of the scriptural scenes, *"Some of these designs display certain peculiarities, such as for instance two scenes being included in one panel, without division"* (Kirby 1965: 119). This occurrence can also be seen in the windows of Queen's College chapel and University College chapel. It is possible that some of the windows in Christ Church also displayed this peculiarity. Another example of Van Linge style work outside of Oxford is a small window in a parish church in Compton near Guildford. This has close analogies with the work of the Van Linges, and although of a similar style to the work of the Van Linges, this window is described as not being up to the usual standard of these artists. It has been hypothesised that this window was created by someone trained by the Van Linges (Rackham 1942).

3.5.1 Post Van Linge: Giles, the Prices and Oliver

The first English glass-painter after the Van Linges was Henry Giles c.1687 he completed some of the Van Linges unfinished works in Oxford and is believed to have been one of their pupils (Eden 1913); Giles lived and worked in York establishing a school of glass-painting there. Although Giles did not paint any of the cathedral windows his work can be seen in the East window of University College, Oxford ("J.S." 1807). The Prices (William Price the elder, William Price the younger and Joshua Price) were of the Giles School of glass-painting, and their work can be seen at Oxford, again in the Colleges. William Price the elder painted the now lost 'Nativity' east window at

Christ Church in 1696 from a design by Sir James Thornhill (Dallaway 1806); and Joshua is said to have been responsible for the repairs and restorations that were made to some of the earlier Van Linge windows in Queens College (Sherwood & Pevsner 1975). Figure 3-31 shows the east window of Queen's College Chapel, the majority of which is painted by Van Linge, but with restoration work by Price. If the Prices were from the Giles school of glass-painting and Giles was himself inspired by the Van Linges, it makes sense that the Prices would have been involved with the Van Linge restorations.



Figure 3-31 Queen's College Restorations by Price

The final glass painter associated with Christ Church cathedral is J. Oliver. Oliver gifted a window to the cathedral that he painted himself at the age of 84 in the year 1700 (Unknown 1845). The image was of St Peter being released from prison by an angel. The identity of Oliver is much debated in the literature; there are those authors, who interpret the signature of J. Oliver as being Isaac Oliver the glass painter (Britton 1821; Walcott 1858; "J.S." 1807), while others say it is the mark of John

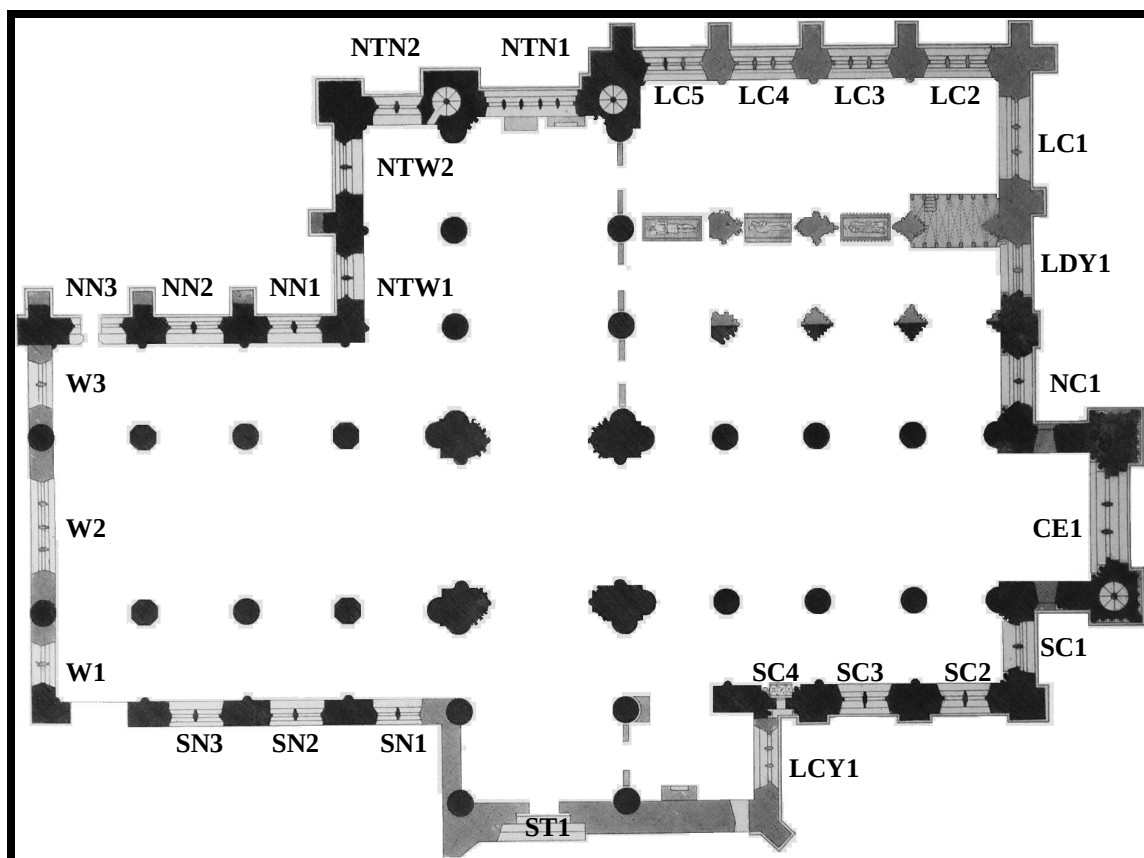
Oliver or another relative of Isaac Oliver ("E.M.S." 1817). Beyond this, very little is known of the artist, a J. Oliver painted windows in Bedfordshire in 1664 ("E.M.S." 1817), if it were the same painter he would have been 48 at the time. But, as discussed later, although the work of both Price and Oliver were painted and installed after the iconoclastic acts of the Civil War era, they did not live up to the Victorian ideals required for the cathedral and have since been lost.

3.6 The Current Window Scheme

This thesis is focussing mainly on the painted glass of the seventeenth century, and for this reason the phases of window development have been defined as pre-1630s, 1630 – 1660 and post 1660s. It will be shown that in the post 1660 period, the painted windows are moved around the cathedral with relative frequency. In order to keep track of where windows are located in the building at any given time, a system for numbering the windows has been developed. Each window has been given a code based on its location within the cathedral, as is shown on the plan Figure 3-32. When analysing the texts written about the cathedral and in particular the Van Linge windows, the location of the window will be added in square brackets. Some of the chapels within the cathedral are known by several names, and these can be confusing, Table 3-2 shows the different names of the chapels within the cathedral, the names in bold are the ones referred to throughout this thesis.

Latin Chapel	St. Fridewide's Chapel	Divinity Chapel
Lady Chapel	St Mary's Chapel?	Dean's Chapel
Lucy Chapel		

Table 3-2 Table of Chapel names



Code	Location
W	West End of Nave
NN	North Nave Aisle
NTW	North Transept West
NTN	North Transept North
LC	Latin Chapel
LDY	Lady Chapel
NC	North Choir Aisle
CE	Choir East End
SC	South Choir Aisle
LCY	Lucy Chapel
ST	South Transept
SN	South Nave Aisle

Figure 3-32 Plan of cathedral with window location codes

3.7 Pre 1630s

Christ Church did contain stained glass windows prior to Dean Brian Duppa's renovation in the 1630s, because fragments of earlier, medieval glass still survive in the cathedral today; but the original location of these windows can be debated. There is some controversy over whether the 14th century windows in the Latin Chapel are in situ

or not [LC3 – LC5]. Gutch (1786) claims that during the 1630s all of the old windows were removed except for four situated in the Latin Chapel. Sherwood and Pevsner (1975) say that the 14th century glass located in both the Latin Chapel and the Lucy Chapel (east end of the south transept) [LCY1] are in situ, although they may have had some restoration work. This is in contrast to the writers of the 19th century, such as, Winkles (1889), Trash (1849), King (1862), Parker et al (1858) and Thompson (1899), who all acknowledge the presence of early glass in the cathedral but all of whom give alternative locations for it. Winkles (1889), in particular, says that Dean Liddell restored the 14th century glass to its original locations within the cathedral, presumably where it remains today [LC3 – LC5]. It is possible that the 14th century glass may have originally been located in the Latin Chapel as this was built during the first half of that century (King 1862). An image from the 1860s (Figure 3-33) shows one of the Latin Chapel windows apparently filled with plain glass, which further supports the idea that the windows have been moved. Other early glass (although no date is given) is described as being located in the west window [W2] (Parker et al. 1858; King 1862; Trash 1849), and the murder of Thomas à Becket is mentioned in the central light of the north transept window [NTN1]. Parker et al (1858) also refer to some old glass depicting the crucifixion located in the east window of the Lady Chapel [LDY1]. But, it is unknown whether these examples were in their original locations or not, or in fact whether they were even complete.

The pre-1630s glass which is mentioned as being in the cathedral include an image showing the crucifixion, the martyrdom of Thomas à Becket, St Augustine, St Blaise, St Martin, St Frideswide and her parents, St Catherine and St Lucy (Parker et al 1858). Sherwood and Pevsner (1975) describe fragments of 14th century glass such as the head of a monk, but it is not certain where these have come from or what size the window they originated from may have been. It has been hypothesised that the pre-1630s windows are *in-situ* but there is also documentary evidence to suggest that the windows may not always have been in their current locations.

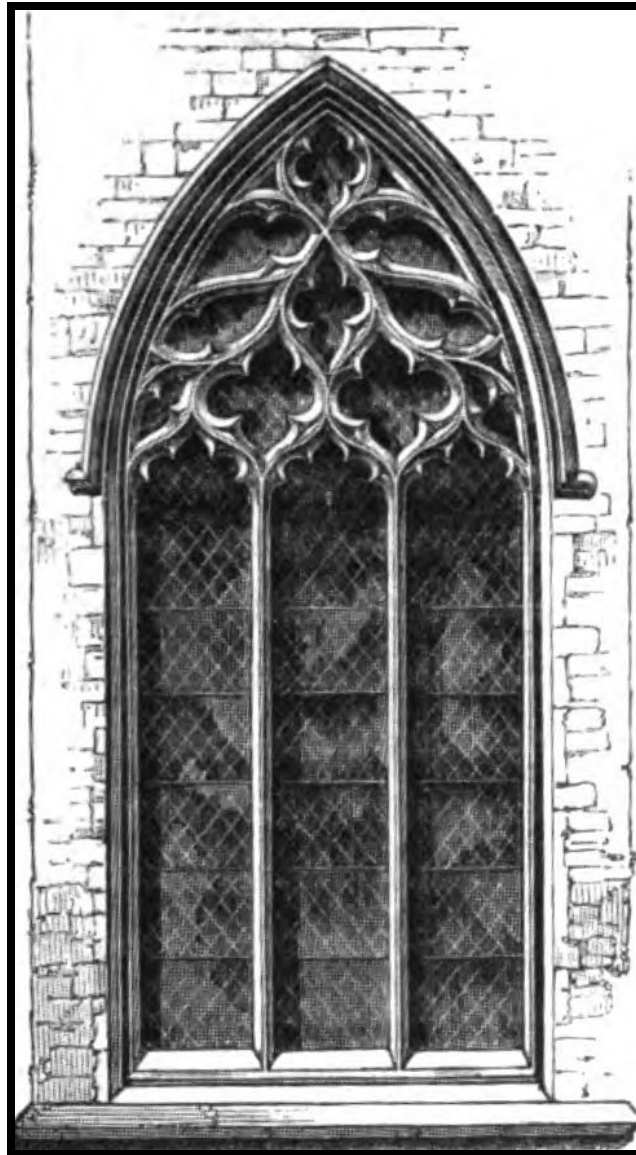


Figure 3-33 A Latin Chapel window apparently filled with plain glass (King 1862: 25)

It is unknown how many of the cathedral windows would have been decorated with medieval glass, or the size and extent of these windows. According to Parker et al (1858) the west window [W2] was filled with Saints Augustine, Blaise, Martin, Frideswide and her parents, Catherine and Lucy. King (1862) states that the west window [W2] contained fragments of 14th and 15th century date but does not add any further description or information about them. Gutch (1786) says that the upper part of the west window [W2] contained the Cardinal's crest, ensign and the see of York. From the descriptions given by these authors it is likely that the west window was by the time of their writing made up from fragments of early glass and that this is likely to have come from other early windows around the building which were removed during the

1630s onwards. Although the pre-1630s glass can be discussed in terms of images, the locations and extent of the windows from which the glass came is debatable.

The 'Becket' window currently located in the upper lights of the east window of the Lucy Chapel [LCY1] is mentioned in this location from 1889 onwards, prior to this component parts of the window are mentioned in the west window [W2] or in the case of the 'martyrdom of Becket' it is said to have been in the central light of the north transept window [NTN1]. Therefore, it is likely that the early 14th century glass was placed in its current location during Dean Liddell's restorations of the cathedral in the 1870s. It is possible that Liddell restored the glass to its original location, but, a closer inspection of the images suggests that they do not exactly fit into the lights which they now occupy. St Augustine preaching, St Martin dividing his cloak with a beggar and St Blaise, now in [LCY1] are all mentioned in as being in [W2]. The other parts of the 'Becket' window are not mentioned specifically and so may have been incorporated in other windows; also mentioned as being in the west window are the images of St Frideswide and her parents, St Catherine, and St Lucy. It is possible that the image of St Frideswide and one of the images of St Catherine, now in the Latin Chapel [LC5 or LC3] may have been the images in the west window, but, this leaves the question, what happened to the images of St Frideswide's parents and St Lucy? It may be possible that all of these images, 'Frideswide and her parents', 'Catherine' and 'Lucy' were the three images that would have been in the fourth Latin Chapel window [LC2].

The only other mention of early glass is in the east window of the Lady Chapel [LDY1], this is said to be the crucifixion and the two Maries depicted in the letters IHC (Parker et al 1858). This glass can currently be seen in one of the windows of the Chapter House (Figure 3-34).



Figure 3-34 Early glass from the Cathedral currently located in the Chapter House



Figure 3-35 Pre-1630s Plan of cathedral

To summarise, the pre-1630s cathedral had an undetermined amount of glass dating from the early 14th century through to the 15th century (Figure 3-35). Four windows in the Latin Chapel [LC2-LC5] were supposed to have remained in place during the 1630s renovations. It has been suggested by some authors that three of the current windows in the Latin Chapel [LC5-LC3], and the upper lights of the window in the east end of the Lucy Chapel (the ‘Becket’ window) [LCY1], are still *in-situ*, there is substantial evidence to suggest that this is not the case, although, the glass may have been restored to its original locations. In all, although the cathedral would have contained stained glass pre-1630, and some of this survives today, the pieces which remain are small and fragmentary and do not constitute a complete window.

3.8 1630-1660

There are two surviving windows from the 1630s, ‘Jonah before Nineveh’ and ‘Bishop King’ both painted by the Van Linges. As mentioned previously, ‘Jonah before Nineveh’ is a pictorial, scriptural scene of the prophet in the foreground contemplating

the city of Nineveh in the background. 'Bishop King' is a painting of a single figure in clerical robes, standing in front of the remains of Osney Abbey. Other than these two surviving windows, virtually nothing is known about this period of the cathedral glass history from contemporary sources. Although there is mention of other Van Linge windows this is mostly from later authors, after the windows had been removed and subsequently restored.

However, there is one text that describes in detail the windows in Christ Church, Oxford. This text is a poem which was written at an unspecified date, but, because it describes the painted windows (one of which is dated 1631), it must have been written during the 1630s and is unsigned.

3.8.1 The Poem: 'A Defence of the Historically use of the painted windows in Christ Church against a Banbury Brother'

The original poem can be found in the British Library manuscript collection *Sloane MS 1435 pp122-124*. It was originally housed in the British Museum as part of *Bagford's Collections of Printing etc*. The exact date and author of the poem is unknown, although, it is suggested either a student of the university (most of the poems in *Parnassus Biceps* were written by students) or even Abraham Wright (who published the poem in 1656) wrote the original (Wright & Beal 1990). Wright and Beal (1990) also say that all the poems in the volume *Parnassus Biceps* were written and circulated in the period 1610-1640. The Van Linge window scheme was begun in the 1630s and took several years to complete; therefore the original poem must have been written towards the end of the 1630s.

The poem can be broken down into three sections; the first section is a response to (presumably) the Banbury brother whose comments occasioned the poem to be written in the first place. It describes some of the renovations instigated by Dean Duppa, and how these have been interpreted, for example, lines 7-8 of the poem, "To whose pure Nose our Cedar gave offence, Crying it smelt of popish Frankincense" this is referring to the wood installed in the cathedral. Also, in lines 9-10 "Who walking over our Marble scoffing said, Whose Bones are underneath these TombeStons laid" this refers to the new marble floor also installed in the 1630s. It is in effect a commentary on how the Puritans were viewed. This can be seen in particular in lines 23-26 "Tis only

some base niggard Heresie, To think Relligion loves Deformitie, Glory did never yet make God ye Lesse, Neither can Beautie defile Holinesse". The poet asks what is wrong with glorifying God and the Bible and he states that just because someone once worshipped an image does not mean that people will do that now, no matter how beautiful the images may be "*Suppose that ignorant Heathen once did bow, To Images, may wee not see them now, Shall wee love Darkness & abhorre ye Sun, 'Cause Persians gave it Adoration*" (lines 77-80). Parallels are also drawn between Roman Gods worshipped for providing bread and wine, and the bread and wine being used to celebrate the Eucharist. "*Though wine for Bacchus, Bread for Ceres went, Yet both are now us'd in the Sacrement*" (lines 83-84).

The second part of the poem describes the painted 'historical' or scriptural windows in Christ Church, and how each window depicts a passage or chapter from the Bible. The descriptions from the poem will be covered in detail later. The third part of the poem asks the question, 'why should the features of Christ Church be seen as idolatrous?' "*But though these various shades delude ye Sense, They never worke upon the Conscience, They cannot make us kneele wee are not such, To thinke ther's Balsame in their kisse or touch*" (lines 169-172). The poet asks why images and statues of rich people can adorn the churches but not images of saints. "*How many Images of great Heires which, Had nothing but the Sin of being rich, Shine in our Temples? kneeling always ther, Wher when they were alive they'd scarce appeare*" (lines 181-184). The poem ends by pointing out that it is one religion expressed in a slightly different way, i.e. it makes use of painted windows and rich decoration to glorify God and to teach the masses. "*Tis not a new Relligion wee have chose, But the same Body put in better Cloathes*" (lines 224-225).

Following is a detailed examination of the text of the poem which describes the painted windows in Christ Church.

*"Looking upon the Resurrection
Mee thoughts I saw ye blessed vision
Wher not his Face was only drawne but minde
Which not with Paint but oile of Gladnesse shin'd."* (Lines 97-100)

The Resurrection – Matt 28: 1-8; Mark 16: 1-10; Luke 24: 1-12; John 20:1-10
– This passage states that the image in this window is the resurrection; it describes the face of Jesus as being painted so that it shines with radiance rather than just paint. This

may be an effect of the light shining through the window based on the window's location, or it may simply be the poet expressing his artistic appreciation.

*“But when I view’d ye next Pane wher wee have
The God of life transported to the Grave
Light then is darke all being so dull & dead
As if that part o’th window were all Lead”* (Lines 101-104)

The Tomb – Mark 15: 46-47; Luke 23: 53-54 – In a window next to the Resurrection, defined because the poet states *“when I viewed the next pane”*, is a description of the internment of the body of Jesus. The window is described as being dark and dull, again, this may refer to the positioning of the window in an area of limited light, or it could just be a reference to the talent of the artist in depicting a dull and lifeless scene in such a way that the ‘audience’ could still find the image realistic.

*“Jonas his whale did all mens eyes so foole
That they’ld have beg’d it for th’ Anatomie Schoole
That he saw Ships at Oxford one did sweare
Although the Thames will hardly beare”* (Lines 105-108)

Jonah and the Whale – Jonah 1:17 – This window describes the story of Jonah; from the poet’s description, it is probable that the image in the window is shortly after Jonah has been cast overboard from the ship, and is subsequently swallowed by the whale. The image is described as being so life-like that the students of the Anatomy School would have wanted it for their collection. Other examples of Van Linge ‘Jonah’ windows can be found in Lincoln and University College Chapels (Figure 3-36), these windows depict scenes similar to the poet’s description.



Figure 3-36 'Jonah' windows
Left: Lincoln College Chapel; **Right:** University College Chapel

*"See in what Awe Moses his rod doth keepe
 The Seas as if a Frost had glas'd ye Deepe
 The Raging waves are to themselves a Bound
 Some cry Helpe, Helpe, or Horse and Man are drown'd,"* (Lines 111-114)

Moses parting Red Sea – Exodus 14: 15-31 – In this section, the poet is describing how Moses raised his staff and parted the waves of the red sea, allowing the Israelites to pass through safely while Pharaoh's men were drowned. The use of the word 'then' at the start of this 'verse' implies that this window is next to 'Jonah and the Whale'.

*"Shadowes for Substance every wher doe passe
 You'd think ye Sand were in an Hower Glasse
 You that have liv'd with Surgeons have you seene
 A Spring of Blood forc'd from a swelling veine,
 So from a Touch of Moses Rod does Jumpe
 A Cataract, the Rocke becomes a Pumpe;
 At sight of whose o'reflowing many get
 Themselves away for feare of being wet"* (Lines 115-122)

Moses Desert Spring – Exodus 17: 1-7 – This window has a longer description in the poem than some of the other windows, it describes the journey of the Israelites through the desert. In the Bible, the Israelites complain of lack of water and God commands Moses to strike a rock with his staff and water pours forth. The poet has described the image in the window as being as vivid as if blood was forced from a swollen vein, the poet achieves this by asking the reader whether they have ever seen the work of the surgeon, ‘Chirurgeons’. The image is apparently so vivid and the representation of the water so life-like that people would want to move away in case they got wet.

*“Have you beheld a sprightly Lady stand
To have her Beame drawne by the painters Hand.
Such lively looks & Colours, such a Dresse
King Pharaoh’s Daughters Image does expresse
Looke well upon her Gowne and you will sweare
The Needle not ye Pencill had bin ther
At sight of her some Gallants doe dispute
Whether i’t Church tis lawful to salute”* (Lines 123-130)

Moses in the Bull-rushes – Exodus 2: 5-10 – This is another slightly longer description and this paragraph needs slightly more interpretation. The clue to the image is the mention of Pharaoh’s Daughter. The poet describes her clothing in great detail, and alludes to her beauty, but beyond this does not mention much else in the window. The only Bible story with reference to Pharaoh’s Daughter is ‘Moses in the Bull-rushes’, and it would make sense to have the all of the Moses stories together in the cathedral.

*“Next Jacob kneeling wher his kidskins such
As it may well cozen ould Izaacks touch”* (Lines 131-132)

Jacob and Isaac – Genesis 27: 18-29 – This image is located next to the ‘Moses in the Bull-rushes’ window, the poet specifically says ‘next’, as though walking around the building. According to the poet, the window depicts Isaac bestowing Esau’s birthright onto Jacob disguised as his brother.

*“A Shepeard seeing how Thornes ’twine’d about
Good Abrahams Ram would needs have help’d it out”* (Lines 133-134)

Abraham and Isaac – Genesis 22: 2-14 – This window would have depicted Abraham attempting to sacrifice his son Isaac to God. Abraham was prevented from

killing his son at the last minute by an angel and they saw a ram trapped in some thorns which was then sacrificed in place of the boy. We have examples of this theme in the college chapels of Wadham (Figure 3-37) and University (Figure 3-38). In both of these surviving Van Linge windows Abraham and Isaac forms the focus of the lights in question, but, in Van Linge windows found in Queens College chapel, the obvious focal point of the window is usually not the major point of a biblical story. For example, the image of the crucifixion is secondary to the last supper. It may be possible that the focus of the cathedral window was on the ram itself, while Abraham and Isaac were given a more background role.



Figure 3-37 'Abraham and Isaac' – Wadham College Chapel



Figure 3-38 ‘Abraham and Isaac’ – University College Chapel

*“Behold ye Dove descending to inspire
Th’ Apostles Heads with cloven Tongues of Fire
And in a superficies ther you see
The grosse Dimensions of Profunditie
Tis hard to Judge which is best built or higher
The Arched Roofe i’t’h window or ith quire”* (Lines 135-140)

Pentecost – Acts 2: 1-4 – This description is interesting to interpret, the first two lines describe the Holy Spirit descending to the Apostles, or the act of Pentecost. The next four lines are describing the above act as taking place inside a temple or other suitable building. The poet compares the Van Linge roof with the cathedral roof, and by

doing so not only implies that it is a grand building in which the Apostles are gathered, but also that the artists had great skill in painting an accurate building interior. A Van Linge depiction of Pentecost can be seen in Queen's College Chapel (Figure 3-39).



Figure 3-39 Image of 'Pentecost' window from Queen's College Chapel

*“So beasts as in the Arke are lively donne
Nay you may see the Shadow of the Sun,”* (Lines 141-142)

Noah’s Ark – Genesis 6-9 – These lines depict the animals on the Ark, probably after the rains have stopped and when the flood was beginning to subside, because the poet specifically mentions the Sun.

*“Upon a Landskip if you looke a while
You’ld thinke the Prospect at least fourty mile,
Ther’s none needs now goe Travell they may see
At home Jerusalem and Nineveh”* (Lines 143-146)

Jonah before Nineveh and The Entry to Jerusalem – Jonah 4: 5; Matt 21: 1-11; Mark 11: 1-11; Luke 19: 28-40; John 12: 12-19 – These two lines are of particular interest, because if it were not for the surviving Van Linge window in the cathedral showing Jonah before the city of Nineveh, then these lines could easily be overlooked. The only reference to the ‘Jonah before Nineveh’ window in the entire poem is the one word ‘*Nineveh*’. The overall implication of these two lines is that the entire of the cities of Jerusalem and Nineveh can be seen within the glass. Because the word ‘*Nineveh*’ refers to an entire window, it is probable that the same is true of the word ‘*Jerusalem*’. As it has been shown, the poem was altered between first ‘authorship’ and later publication. This alteration specifically mentions an ‘Entry to Jerusalem’ window, but who altered the poem and when is unknown. The alteration is probably just Civil War propaganda, but if not, it would mean that another story depicting the city of Jerusalem was present in the window scheme.

*“A Sodome now in Flames one glaunce will Dart
Farther than Linx with Galilæus Art”* (Lines 147-148)

Sodom and Gomorrah – Genesis 19: 23-26 – Here the poet is describing the ‘Sodom and Gomorrah’ window which later authors also describe, hence it must have survived the Civil War and was re-instated into the cathedral. Unfortunately there are no further descriptions of this window. It is always referred to as the destruction of Sodom and Gomorrah, and the poet has in fact stated ‘*Sodom now in flames*’. Fragments from this window can be found amongst those installed in the clerestory lights and west windows of the north transept (Figure 3-40). The existing fragments show a city in flames, and Lot’s wife depicted as a pillar of salt. This text also has the interesting reference to the distances depicted in this window. The poet refers to a *Linx* meaning the big cat Lynx, and referring to their sharp eyesight. Also, ‘*Galilæus*’ is referring to

Galileo, it was in 1609 that he invented his telescope. This would imply that the window was illustrating a great distance in such a way that the ‘audience’ would not need the sharp eyes of a Lynx and a telescope.



Figure 3-40 ‘Sodom and Gomorrah’ fragments

*“Seeing Elijahs Chariot wee feare
Ther is some firie Prodigie ith Aire”* (Lines 149-150)

Elijah’s Chariot – 2 Kings 2: 1-14 – The window the poet is describing is the ‘taking-up’ of Elijah in a fiery chariot. Examples of similar themed Van Linge windows can be found in the college chapels of University (an entire window), Wadham and Lincoln (the latter two being images in the lights of multi-story windows) (Figure 3-41).



Figure 3-41 ‘Elijah and Elisha’

Left: Lincoln College Chapel; **Right:** University College Chapel

*“When Christ to purge the Temple holds his whip
How nimbly Hucksters with ther Burdens skip”* (Lines 151-152)

Christ overturns the temple – Matt 21: 12-13; Mark 11: 15-19; Luke 19: 45-48; John 2: 13-22 – In these lines the poet is describing Christ overturning the money-lenders and tradesmen in the temple. Again, an example of a similar theme can be seen in a window in University College chapel (Figure 3-42).



Figure 3-42 ‘Christ Overturns the Temple’ – University College Chapel

*“St Peters Fishes are so lively wrought
Some cheapen them and aske when they were caught”* (Lines 153-154)

St Peter’s miraculous draft of fish – Luke 5: 1-11 – This description is suggestive of St. Peter’s miraculous catch of fish, but beyond this there is no further information as to what might be depicted in this window.

The poem also makes a reference to a Christmas window although it does not describe one:

*“And whereas Feasts come seldome heres espied
A Constant Christmasse, Easter, Whitsontide”* (lines 211-212)

This may indicate either that a Nativity window is present but the author did not feel the need to describe it, or that a Nativity window was in the process of being painted, but at the time the poem was written was unfinished hence the lack of description. Two other Van Linge windows were known to have been in the cathedral, neither of which are mentioned in the poem, these include the unsigned figure of Bishop King, often attributed to Bernard Van Linge (Sherwood & Pevsner 1975), and the depiction of ‘Christ Disputing with the Doctors’ painted by Abraham Van Linge and dated 1640. The presence of the latter window strongly suggests that the scheme was unfinished at the time the poem was written, and that the poem pre-dates 1640.

3.8.2 Other Poems

After the poem was written it was collected together with other poetry and published by Abraham Wright in 1656 in a volume called *Parnassus Biceps*. It is interesting to note that the version of the poem published by Abraham Wright (which is the most widely accessible version) was altered from the original poem, and now includes references to aspects of the Civil War. The original poem is entitled *A Defence of the Historicall use of the painted windows in Christ Church ag^t a Banburie Brother* while the published poem is entitled *A Poem, In defence of the decent Ornaments of Christ Church Oxon, occasioned by a Banbury brother*. At first glance, there appears to be little difference between the two titles, but, the slight language differences have a large effect when considered in the context of the Civil War. For example, the original states the poem is in defence of the ‘*Historicall use of the painted windows*’, this is following the Laudian ideals of improving and beautifying ecclesiastical settings (Lillie 1942). Even Laud at his trial acknowledged that figural images were not necessarily acceptable, as they could be seen as idolatrous, but that windows depicting scriptural history were acceptable and in fact had their uses in teaching and admonishing the people (Lillie 1942). The title of the original poem is therefore telling us that the focus of the piece is in the defence of depicting biblical history in glass. The title of the

published poem suggests that the whole poem is defending everything that could potentially be seen as anti-Puritan or pro-Catholic. Both titles agree that the text was written as a response to what a Banbury brother had said about Christ Church.

The published poem is longer than the original, in several places extra pairs of lines have been added. Some of the language has also been changed, although this may be interpreted as updating the English language. Most of the changes relate to the Royalist and Laudian causes, for example, in the original poem references are made to beautifying churches, whereas in the published version this is changed to altars. One of Laud's changes was to reinstate the position of the altar (Norton 1864). The original poem is 225 lines long, while the published poem is 264 lines in length, so an extra 39 lines have been added.

Most of the alterations to the poem occur in the third part, the exception to this is the addition of two lines in the window descriptions "*See in what state (though on an Asse) Christ went, This shows more glorious than the Parliament*" (lines 111-112 published). Two events relating to Parliament occurred during the 1640s to which the poet could be alluding in these lines. The first was in November 1640, Charles I called together Parliament and it could only be dissolved with the agreement of its members, this became known as the Long Parliament (Adams & Stephens 1930). The second event in 1644, occurred when Charles I moved Parliament from Westminster to Oxford, claiming that the remaining members of the Westminster Parliament were guilty of high treason (Varley 1932). The poet is comparing the state entry of Parliament to the entry of Christ into Jerusalem. If it can be determined which parliamentary event the poet is referring to, then the alterations to the poem can be dated. At the very least, the alterations must have occurred between 1640, when the Long Parliament was called and 1656, when the poem was published.

The other alterations to the poem refer to the 'power' of the images (lines 175-176) "*That were gross superstition we know; There is no more power in them than the Pope's toe*"; lines 183-184 explain how the poet agrees with the puritans, idolatry is bad "*Obedience to blocks deserves the rod; The Lord may well be then a jealous God*". The next addition is 12 lines long and talks about how the images in Christ Church can be used to educate the illiterate (lines 211-222).

*"Cease then your railings and your dull complaints;
To pull down Galleries and set up Saints*

*Is no impiety: now we may well
 Say that our Church is truly visible:
 Those that before our glass scaffolds prefer,
 Would turn our Temple to a theatre.
 Windows are Pulpits now; though unlearned, one
 May read this Bibles new Edition.
 Instead of here and there a verse adorn'd
 Round with a lace of paint, fir to be scorn'd
 Even by vulgar eyes, each pane presents
 Whole chapters with both comment and contents"*

This is followed by an addition of 4 lines (229-232) which describe how these windows can also be used to teach the scripture to the deaf, because although they cannot hear the message, they will now be able to see the message. *"Let the deaf hither come; no matter though Faiths sence be lost, we a new way can show: Here we can teach them to believe by the eye; These silenced ministers do edify"*. Two lines describing how Paul's doctrine can be illustrated in a clearer way (lines 241-242) *"Hence then Pauls doctrin may seem more divine, As Amber through a Glass doth clearer shine"* have been added. Also, a single line *"Than there is in the Practise of piety"* (line 246) has been added, this is presumably in order to form a rhyming couple with the previous line (which originally had no partner line) *"Thus then there's no more fault in Imagry"* (line 245). The final 14 lines that have been added to the published version of the poem explain how the puritans' felt that the images in the glass were distracting to those in church, while the poet claims that the images are just images to help the faithful focus on the divine (lines 251-264).

*"You'll say they make us gaze when we should pray
 And that our thoughts do on the figures stray:
 If so, you may conclude us beasts, what they
 Have for their object is to us the way.
 Did any ere use prospectives to see
 No farther than the Glass: or can there be
 Such lazy travellers, so given to sin,
 As that they'll take their dwelling at the Inn.
 A Christian's sight rest in Divinity,
 Signs are but spectacles to help faiths eye,
 God is the Centre: dwelling on these words,
 My muse a Sabbath to my brain affords.
 If their nice wits more solemn proof exact,
 Know this was meant a Poem not a Tract."*

There are a number of other poems written around the same time which all refer to a specific window or windows, but none of the other poems go into detail as to the images or the locations of the windows, other than to say that they are of scriptural stories. Most of the references to the Van Linge scheme in these poems are oblique, for full texts of the poems see appendix A. *On Christ-church windowe, and Magdalen Colledge wall* was written by J. Mennis in 1656, the poem describes a painted wall in Magdalen College, Oxford. The painting depicts the story of Christ from his birth through to his ascension. The poet goes to great lengths to praise the wall, and says at the end of the poem that “*But Ile not prayse our own, ‘tis far more fit To leave the talke to some fine Maud’lin wit*” (Mennis 1656 lines 135-136), this implies that because he has praised their painted wall, they should praise the Christ Church window in return. The last 16 lines of the poem are about Christ Church’s east window, this is highlighted by lines 127-128 which say “*let any wise man bend His eyes towards our orientall end*”. The poet also describes how anyone approaching the window will mistake it for a wall, “*Hee’le blesse himselfe indeed, grow wise; withal Approaching take the window for a wall*” (lines 129-130) this implies that the window is a pictorial window, as large wall spaces were often filled with paintings. The poet also says that Wadham and Lincolns ‘types’ are outdated, “*And then conclude that Wadehams perspective Nor Lincolnes stately types can long survive; They’le break for envie (spight of wise) to find Us to transcend themselves so farre behind*” (lines 131-134); both Wadham and Lincoln’s east windows are made up of types and anti-types. This suggests that the east window of Christ Church is a single Bible story or series of biblical passages, rather than types and anti-types. The poet does not however actually say what the image on the east window of Christ Church is.

On The Imperfection of Christ Church Buildings was written by William Cartwright, a Student of Christ Church between 1611 and 1643. The poem describes the unfinished state of the college, but also explains how the college was spared by Henry VIII, and how the structure survived the troubles that occurred between 16th and 17th centuries. In lines 41-46, the poet explains how both Christ Church and St Paul’s in London, were in need of repair, and that renovation was granted to St. Paul’s, and how the members of Christ Church were hoping that someone would offer the same financial aid to them. But in lines 47-48 when the poet says “*But ruins yet stand ruins, as if none*

Durst be so good, as first to cast a stone”, he is implying that the college is still undergoing renovation, or is still in need of repair. The poet goes on to specifically mention the cathedral, in lines 53-54 he says “*But what’s new given; unto ourselves we owe That skulls are not our Church’s pavement now*” this suggests that Brian Duppa had installed the new marble floor and that the old tombstones had been moved at the time the poem was written. The poet also mentions that the Van Linge windows have been installed, and again implies they are descriptive, pictorial windows “*That now our windows may for doctrine pass, And we (as Paul) see mysteries in a glass*” (lines 59-60). Other than explaining that the cathedral windows are of scriptural stories, no further mention is made of them. It can be deduced that most if not all of the windows in the building were scriptural stories because the poet specifically says ‘windows’.

3.8.3 The Van Linge Scheme

The Van Linge scheme would have been one of the largest in the country installed between 1630 and 1640 (Power & Shortland 2007), but the only descriptive text of the windows is the anonymous poem described above, and no other evidence as to the nature or structure of the scheme has been discovered. The order in which the windows would have been placed is therefore open to interpretation. The first window to deal with is ‘Bishop King’; this is a small window and fits the old Norman window space. There are only three locations in the cathedral where this window could have been placed without having to change the architecture of the window. These locations are [SC4] or one of the two Norman arch windows either side of the east window. These latter two were supposedly blocked until Liddell re-opened them (Winkles 1889); therefore, the ‘Bishop King’ window is most likely to be in its original location. This window space is interesting as unlike other window spaces it has the wall of the Lucy Chapel next to it, thereby preventing the size of this window being changed.

The pictorial windows which were definitely described by the original poem are:

- The Resurrection
- The Tomb
- Jonah and the Whale
- Moses parting Red Sea
- Moses Desert Spring
- Moses in the Bull-rushes

- Jacob and Isaac
- Abraham and Isaac
- Pentecost
- Noah's Ark
- Jonah before Nineveh
- Jerusalem
- Sodom and Gomorrah
- Elijah's Chariot
- Christ Overturns Temple
- St Peter's Fish

The published version of the poem makes a direct reference to the 'Entry of Christ to Jerusalem' and both poems say that Christmas, Easter and Whitsun are represented in the glass. Therefore, it can be hypothesised that a 'Nativity' window was either present or in the process of being made in terms of the original poem. 18th and 19th century authors often make reference to a 'Christ Disputing with the Doctors' window, suggesting that this too would have been part of the scheme; this totals 19 Van Linge scriptural windows, plus the non-scriptural Bishop King, bringing the total number of windows in the scheme to 20.

The next earliest available text written about the windows is the work of Anthony Wood (Wood quoted in Gutch 1786) who states that four early windows were saved. This is most likely to be the Latin Chapel windows which have retained their architecture throughout. The addition of the 4 Latin Chapel windows brings the total to 24 windows. The plan of the cathedral shows 27 window spaces. The two window spaces either side of the west window are also slightly smaller in size; one of these is the current location of the 'Jonah before Nineveh' window, and as has been mentioned earlier, the 'Jonah' window does not fit this space. Therefore, it is unlikely that that these would have had Van Linge images. One window space in the south transept [opposite NTN1], where the 'Tree of Jesse' window is currently located, is unusual as this window is wide and short and therefore also an unusual shape compared to the other cathedral windows.

The language used in the poem can help to determine where specific images would have been located in the scheme. For example, line 101 "*But when I viewed the next pane*", this could either mean the next 'light' within the same window, or it could mean the next window. The way the poem is written suggests to a certain extent that the author is walking around the building and describing each window in sequence. The

problem with reconstructing this approach is that not all the windows were present when the poem was written, suggesting that the scheme was unfinished. The author of the additions only adds one extra window to the descriptions, the 'Entry to Jerusalem', at the time the additions were written, the 'Christ Disputing with the Doctors' window, dated 1640, would have been finished. This latter window is not mentioned in the amended poem as the alterations were in response to the attitudes of the 'Civil War', and there was no need to mention the 'Christ Disputing with the Doctors' window. Also, if a 'Nativity' window had been created, it would not need an additional description as it had been mentioned in passing in the original poem.

There are a few assumptions that have been made in the reconstruction of the scheme:

- All images mentioned in the poem occupy separate windows
- The majority of the images in the poem are in the order they appeared in the cathedral
- Multiple windows relating to the same story would have been located next to each other
- The three 'seasonal' windows i.e. Christmas, Easter, and Whitsun would have occupied the three main focal windows i.e. west, north, and east.
- The scheme was unfinished when the poem was originally written
- Four 14th century windows were left in the Latin Chapel

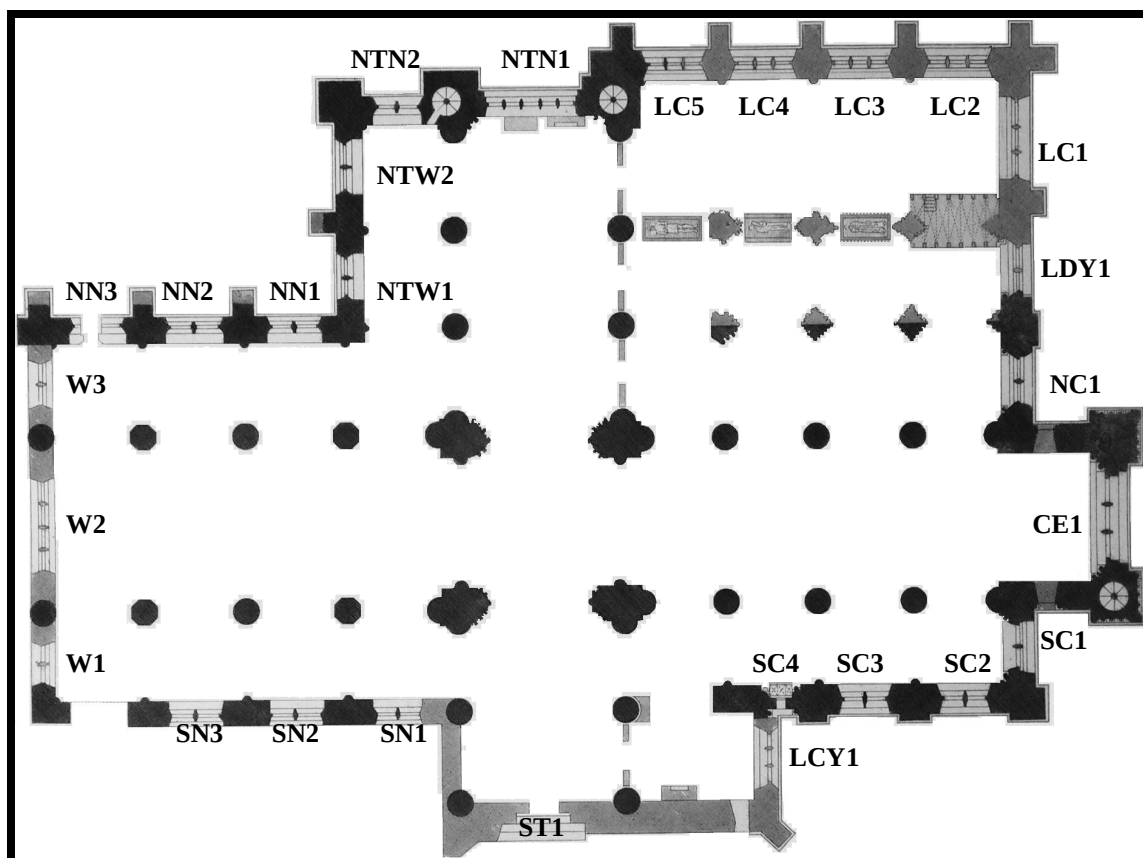


Figure 3-43 Plan of the available window spaces in Christ Church

The first description in the poem is the Resurrection; the logical place for this image would be the east window [CE1] (Figure 3-43). The Resurrection is the centre of the Christian belief and in most ecclesiastical settings where this is depicted it appears above the altar. The poem then says that the next pane is the Tomb “*But when I viewed the next pane*” (line 101). In order for the poem windows to fit the cathedral windows, and for Christmas, Easter and Whitsun to fit in the west, north and east windows, there is only one direction around the building that the poet could have walked. In this case ‘the Tomb’ would have been located in the east window of the south choir aisle [SC1]. Although no ‘Crucifixion’ window is mentioned in either poem, it seems strange that the Resurrection and the Tomb would be present without a depiction of the Crucifixion. I therefore propose that a depiction of the Crucifixion would have been present. In this case the logical place for the Crucifixion would be next to the Tomb in [SC2]. This would mean that if one was facing the altar, the story of Jesus’ last days would be in order.

Next the poem mentions ‘Jonah and the Whale’, but it also says in the original that the image after ‘Jonah’ is ‘Moses parting the Red Sea’ “*Then in what awe Moses*

his rod doth keep” (line 113 published). One of the assumptions above is that multiple windows relating to the same story would be placed together, therefore somewhere next to the ‘Jonah and the Whale’ window is the ‘Jonah before Nineveh’ window. The poet does not specifically describe ‘Jonah before Nineveh’, this window is only ever mentioned in passing, and it is possible that this window is slightly apart from its partner window. Wood (quoted in Gutch 1786) mentioned that Dr King donated all the windows of the south aisle, but the inscription on the ‘Jonah before Nineveh’ window is that it was donated by Charles Sunibank. Therefore, ‘Jonah and the Whale’ could be located in [SC3] and ‘Jonah before Nineveh’ in [LCY1]. This would also ensure that the story of Jonah is in the correct order when facing the altar. In between these windows would be ‘Bishop King’ in [SC4] as this is the only location possible for this window. Because the poem uses the term ‘then’ it suggests that there may be a gap between the ‘Jonah and the Whale’ and ‘Moses parting the Red Sea’ windows, unlike between the Resurrection and the Tomb where the poet specifically says the Tomb is in the next pane. Therefore, ‘Moses parting the Red Sea’ would be located in [SN1].

The poet mentions all three ‘Moses’ windows one after the other in the poem, and if ‘Moses parting the Red Sea’ is in [SN1] then the other two parts of the story would be in [SN2] and [SN3]. The poet then says “*Next Jacob kneeling*” (line 133 published); as mentioned earlier in this section, windows [W1] and [W3] were unlikely to have been used in the scheme, and [W2] is the prominent west window and therefore unlikely to have been the location of the ‘Jacob and Isaac’ window. Window [NN3] is also unlikely to have had an image as this window is directly above the Dean’s door. Therefore, the ‘next’ window which happens to be opposite ‘Moses in the Bull-rushes’ would be [NN2]. Therefore, ‘Jacob and Isaac’ would be in [NN2], followed by ‘Abraham and Isaac’ in [NN1].

The next window mentioned in the poem is ‘Pentecost’; this is one of the ‘big’ Christian festivals and as such is likely to have been given a prominent location. The poet is walking around the cathedral and [NN1] is located at the edge of the north nave aisle and the north transept. The most likely location for ‘Pentecost’ is [NTN1], also from this location the author is in a position to see both the image in the window and the roof of the choir leading to the line “*’Tis hard to judge which is best built and higher The arch roof in the window or the Quire*” (lines 141-142 published). The next story

mentioned is 'Noah's Ark' this would be in [NTW1]. The next passage in the poem mentions both Jerusalem and Nineveh, but does not describe either window. From the poet's location in the north transept it would be possible to view across to both 'Jonah before Nineveh' [LCY1] and the 'Crucifixion' [SC2]. Neither of these scenes is described by the poet but 'Jonah before Nineveh' still exists in the cathedral proving that the poet referred to an entire window in one word. Therefore, the lack of description of the 'Crucifixion' could be covered by the word 'Jerusalem' as the city is likely to have been in the background of the window. Next is mentioned 'Sodom and Gomorrah', the most likely location for this window would be [NTW2]. The last window space in the north transept [NTN2] would then be filled by 'Elijah's Chariot'.

The poet would then move into the Latin Chapel, where four of the medieval windows remained. The end window of the Latin Chapel [LC1] is a bigger window than the other remaining two windows [LDY1] [NC1]. Later descriptions of the 'Christ Disputing with the Doctors' window, dated 1640, always place the window here, which suggests that it fitted this space. At the time the poem was originally written this window would probably have been blank as the scheme was unfinished. Moving into the Lady Chapel, the poet then described 'Christ Overturns the Temple' [LDY1]. Finally in the east end of the north choir aisle [NC1] the poet described 'St. Peter's miraculous draft of fish'.

The west window [W2] is most likely to have been filled with the 'Nativity', but like 'Christ Disputing the Doctors', this window was not in place when the poem was written.

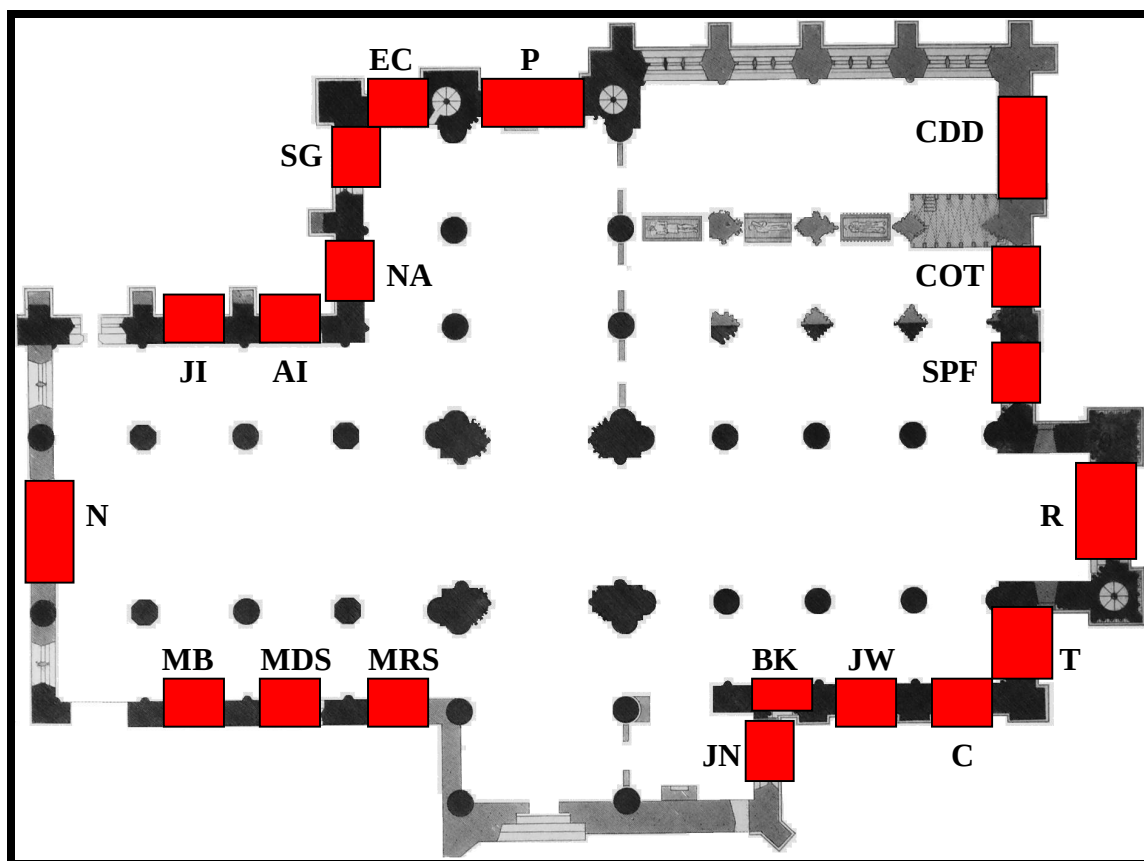


Figure 3-44 The Van Linge window scheme

Code	Window
CDD	Christ Disputing with the Doctors (1640)
COT	Christ Overturns the Temple
SPF	St Peter's miraculous draft of fish
R	The Resurrection
T	The Tomb
C	The Crucifixion
JW	Jonah and the Whale
BK	Bishop King
JN	Jonah before Nineveh (1631)
MRS	Moses parting the Red Sea
MDS	Moses creates a Spring in the Desert
MB	Moses in the Bull-rushes
N	The Nativity
JI	Jacob and Isaac
AI	Abraham and Isaac
NA	Noah's Ark
SG	Sodom and Gomorrah
EC	Elijah's Chariot
P	Pentecost

Table 3-3 Window Names

Looking at this interpretation of the Van Linge scheme, it will be noted that with the exception of 'Pentecost' in the north window and the 'Nativity' in the west window, all the New Testament stories are at the east end of the cathedral. The proximity of 'Jonah and the Whale' to the 'Resurrection' is not as unusual as it may first appear, as the former is the type to the latter's anti-type. Jonah spent three days in the whale and Jesus rose from the dead after three days. In the same vein, the 'Nativity' is near 'Moses in the Bull-rushes', both signifying the birth of a saviour. Finally, 'Pentecost' is located next to 'Elijah's Chariot', both signifying the presence of the Holy Spirit.

To return to the issue of the 'Entry to Jerusalem', this window is specifically mentioned in the published version of the poem "*See in what state (though on as Asse) Christ went, This shows more glorious than the Parliament*" (lines 111-112). The location of this insertion into the poem could be used to give an indication of where it was located in the scheme. For example, the description is not 'tagged' on the end of the window descriptions; it is inserted between 'Jonah and the Whale' and 'Moses parting the Red Sea'. It does not seem likely that the existing scheme would have been rearranged to accommodate one window; it is more likely that a space was deliberately left for this window. The space that would have been available is an odd window where the 'Tree of Jesse' is currently located, in the south transept [ST1]. This window is an odd shape because it is short and wide. If the 'Entry to Jerusalem' were placed in this window, it would create a fourth compass point i.e. the south and it would not be out of place as a major window. This may also explain why, when later reference is made to this image being in the north transept window, it is often described as fragmentary, because it was originally designed for a much smaller window.

The 1630s saw the installation of a scheme of 20 windows, 19 of which depicted scriptural stories and 1 which depicted Bishop King. This scheme took around 10 years to complete, 'Christ disputing with the Doctors' is recorded as being dated 1640, and this was one window not mentioned in the poem. The reconstruction of the scheme proposed here places all the New Testament stories (with the exception of those in north, south and west windows) at the east end of the cathedral. The Old Testament stories fill the rest of the cathedral. Also, all the windows depicting different parts of the same story are grouped together, for example, Jonah in the south-east, or Moses in the

south aisle. The order of the windows follows the order of the stories, with the earliest part of a story in the westerly window of a group.

3.9 Post 1630

The Van Linge scheme was only in the cathedral for a short time (Power & Shortland 2007), several authors have mentioned the painted windows of Christ Church, and in some cases a location of the window has been mentioned, but the accounts are very varied. Following is an analysis of the descriptions of the painted windows, in an attempt to unravel the complex attitudes felt about the windows.

3.9.1 Mundy 1630s, Wood 1668, and Gutch 1786

Peter Mundy writing in the 17th century tells us that the windows were set-up in 1638, “*Christs church, a Cathedrale, allsoe very excellently sett Forth, with Faire windowes off scripture stories in lively coulloured painted glasse, sett uppe butt last yeare, 1638*” (Carnac Temple 1925: 27).

But, Wood (quoted in Gutch 1786) tells us that the windows were installed in 1634, this does suggest that the scheme was installed on a window by window basis and that it was unfinished when it was written about in Abraham Wright’s poem. Abraham Wright’s poem would, therefore, have been written in the latter part of the 1630s.

“*Afterward they took down all the old windows (except four in the Divinity Chapel) [LC2-LC5] which were set up anciently by the Canons of St. Frideswyde’s Priory, containing several parts of that Saint’s life, besides the Arms of many Noblemen that had been Benefactors to that Monastery. Which being done, and the fine Architecture or Crustation of those windows cut and sawn away, they put up new painted windows with several scripture stories in them, admirably well performed by the exquisite hand of Abraham Van Ling, a Dutchman, an. 1634. Some of them were put up at the sole charge of the House, and others by these persons following, viz. BASIL WOOD, LL. D. sometime Fellow of All Souls College, afterward Chancellor of St. Asaph and Rochester, and at length of the diocese of Oxon; EDWARD COTTON, father to Dr. Cotton, who gave to the New Building: Mr. ROBERT BURTON; Dr. CHARLES*

*SUNNIBANK, Preb. Of Windsor; Dr. KING the windows in the south aisle; -----
HEALE of Devonshire the great east window* (Wood quoted in Gutch 1786: 462).

Wood's text suggests that the four windows of the Latin Chapel may have been older in date than the other windows in the cathedral. Wood goes on to describe how the architecture of the removed windows was changed. The style of the windows was changed from three lights to two lights (Winkles 1889), later authors provide images of the Y-tracery in the windows and the existing 'Jonah before Nineveh' window also utilises this architecture. Wood also lists the benefactors of the windows but other than stating that Dr King donated the windows of the south aisle and that 'Heale of Devonshire' donated the east window, he does not go into any detail as to the nature of the windows (Wood quoted in Gutch 1786), or their locations within the cathedral. This is not surprising as Wood's *The History and Antiquities of the Colleges and Halls in the University of Oxford* was first published in 1668, after taking 10 years to complete. This means that by the time Wood was describing the cathedral windows (c.1658) they had already been removed from the building. Wood was probably relying on 'word of mouth' for his narrative, although he may also have used cathedral records, if so, these records no longer survive.

But these windows continuing no longer than till an. 1648, were then, as anti-christian, diabolical, and popish, at first broken; and, to prevent their utter ruin by the restless and never to be satisfied Presbyterians, all taken down. So that possibly had the old windows remained till then they might have stood to this day" (Wood quoted in Gutch 1786: 462-463; Wood 1786: 462-463).

The Van Linge scheme was removed from the windows in the 1640s during the Civil War years (Chalmers 1810). Four Van Linge windows are largely believed to have been returned to the cathedral during the 1660s, and potentially fragments of a fifth (Parry 2006). These windows were:

- 'Jonah before Nineveh'
- 'Sodom and Gomorrah'
- 'Christ Disputing with the Doctors'
- 'Bishop King'

Some authors suggest that fragments of the 'Entry into Jerusalem' also survived (Parry 2006).

Gutch (1786) who published the edited volume of Wood's above work adds a description and location of certain restored Van Linge windows.

"In the Windows in the south Aile, joining to the Body of the Church [W1, SN1-SN3]....Jonah sitting under the Gourd, and viewing Nineveh. 'Carolus Sunbanke Praebendar. Windsor. S.T.P. Hujus Eccl. Loim Alum. D.D.' 'Abraham Van Linge fecit 1631'" (Gutch 1786: 464).

"In the north Aile, joining to the Body of the Church.[W3, NN1-NN3] ... The Destruction of Sodom and Gomorrah, Abraham praying, and an Angel appearing to him" (Gutch 1786: 464).

"In the east Window of St. Frideswid's Chapel, now the Divinity Chapel, on the north side of the Choir. [LC1] Christ disputing with the Doctors. 'Anno aerae Christianae MDCXL. Abraham Van Linge fecit 1640'" (Gutch 1786: 465).

So, Gutch gives the location of three of the surviving Van Linge windows. He also mentions the work of Price in the east window [CE1] and the work of Oliver somewhere in the north aisle [W3, NN1-NN3], and the image of Robert King in the south choir aisle [SC4]. But Gutch does make a curious contradiction; in one of his footnotes relating to Wood's original text he questions whether the Van Linge window commissioned by Heale of Devonshire (the east window) [CE1] was potentially moved to either the large north transept window [NTN1] or to the east window of the Latin Chapel [LC1]. The latter of these positions is also where he has said that 'Christ Disputing with the Doctors' is located. Later plans of the cathedral show that the east window could have fitted into the space at the east end of the Latin Chapel, but 'Christ Disputing with the Doctors' would be an unlikely choice of window to have as the main east window. If Gutch's other hypothesis is correct and that the main east window was moved to the large north transept window, it may give the image the appearance of being incomplete as the image would be too small for the space. Also, if the window was still present when Gutch was writing his descriptions, why does he not describe the window? A possible explanation for this contradiction is that the image in the north transept window, which when described is always referred to as fragmentary, is not an image of the entry into Jerusalem, but is in fact the remains of the east window and depicts the resurrection.

Figure 3-45 is a plan of the cathedral illustrating the window locations based on the work of Gutch 1786.

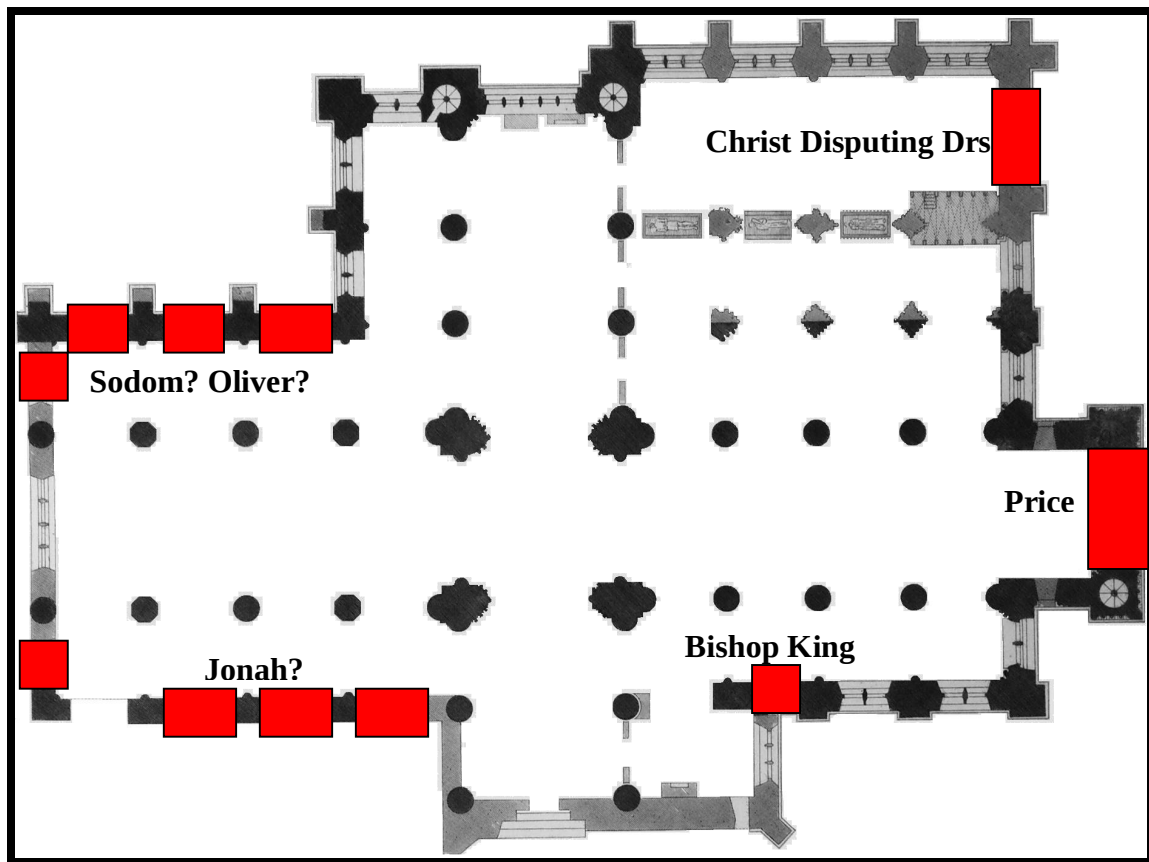


Figure 3-45 Plan of V.L. windows based Gutch 1786

3.9.2 Prince and Cooke 1789

“In the Aisle, South of the Choir, is a good Portraiture in the first Window of Robert King, who was the last Abbot of Oseney, and the first Bishop of Oxford” [SC4] (Prince & Cooke 1789: 77).

Prince and Cooke (1789) also make reference to the Price window *“The East Window [CE1] was painted by Mr Price, senior, of London, after a Design of Sir James Thornhill, representing the Epiphany”* (Prince & Cooke 1789: 77) and the Oliver window *“At the North Corner of the West End [W3] is a Window curiously painted, representing St. Peter delivered out of Prison by the Angel...admirably well drawn: And though a very small portion of the glass is stained, the Colours are brilliant and the Whole appears very lively”* (Prince & Cooke 1789: 77), but there is no specific mention

to any of the Van Linge works in the cathedral. This may mean that within three years of Gutch's work, the Van Linge windows have been removed completely (excepting Bishop King); or, as is more likely the case, this book, entitled '*A new Pocket Companion for Oxford: or Guide through the University*' was too small a book to list all the windows in the cathedral and therefore focussed on the three most interesting windows.

3.9.3 Dallaway 1806

In 1806 Dallaway commented on some of the windows in Christ Church, with reference to Abraham Van Linge he said "*At Christ Church he finished the subjects of Jonah, Sodom and Gomorrah, and Christ with the doctors, with several dates, 1631, 1634, and 1640*" (Dallaway 1806: 279). No further indication is given as to where in the building these images may have been located. Dallaway also mentions the Bishop King window, again without reference to the location, but he does say it was painted by Bernard Van Linge. And, like previous authors he mentions the Price and Oliver windows. Dallaway does make an interesting reference to the 14th century glass "*There are saints with very rich canopies, which were certainly brought from that abbey [Oseney] when destroyed*" (Dallaway 1806: 280). This appears that Dallaway is suggesting that the glass in the Latin Chapel may have originated in Oseney Abbey and been moved into Christ Church. "J.S." in 1807 in *The Universal Magazine* says almost word for word what Dallaway says about the cathedral glass, and again, he does not specify details or locations of the images.

3.9.4 Britton 1821

The next text to really describe and locate the windows is published in 1821 "*The stalls, pavement, and fitting up of the choir, appear to have been executed about the year 1630; and soon afterwards most of the windows were repaired, and painted glass, by Van Linge, inserted. One of these, in the south aisle, containing the story of Jonah, is dated 1631 [W1, SN1-SN3]; another, representing the destruction of Sodom and Gomorrah, was painted in 1634 [W1, SN1-SN3]; and a third, in the divinity chapel, representing Christ disputing with the Doctors, bears the date of 1640 [LC1-*

LC5]. *The principal east window was painted by W. Price, from a design by Sir James Thornhill, in 1696* [CE1].

In the north aisle [W3, NN1-NN3] is a small window, which Mr. Dallaway describes as a 'singular curiosity,' from having been painted by Isaac Oliver in 1700, when he was eighty-four years of age. In a window of the north aisle of the choir [NC1], is a painted full length of Bishop King, supposed by Mr. Chalmers to have been executed soon after the prelate's death" (Britton 1821: 18). It is interesting to note that the author has described the 'Bishop King' window as being in the north aisle of the choir. In this aisle there is one window (at the east end), and Bishop King is too small to fill this space. But, when Britton describes one of the illustrative plates he mentions the south choir aisle as being in a location which is actually the north choir aisle. Therefore, in this way, it is probable that when he refers to the Bishop King window in the north aisle of the choir, he actually means the south, where the window is located today? Assuming this is true, then, it may be possible that Britton is wrong in his locations for the other painted windows. Figure 3-46 shows a cross section of the cathedral, the caption taken from Britton's text describes the Latin Chapel, Lady Chapel and south choir aisle, yet these are all on the north side of the cathedral.

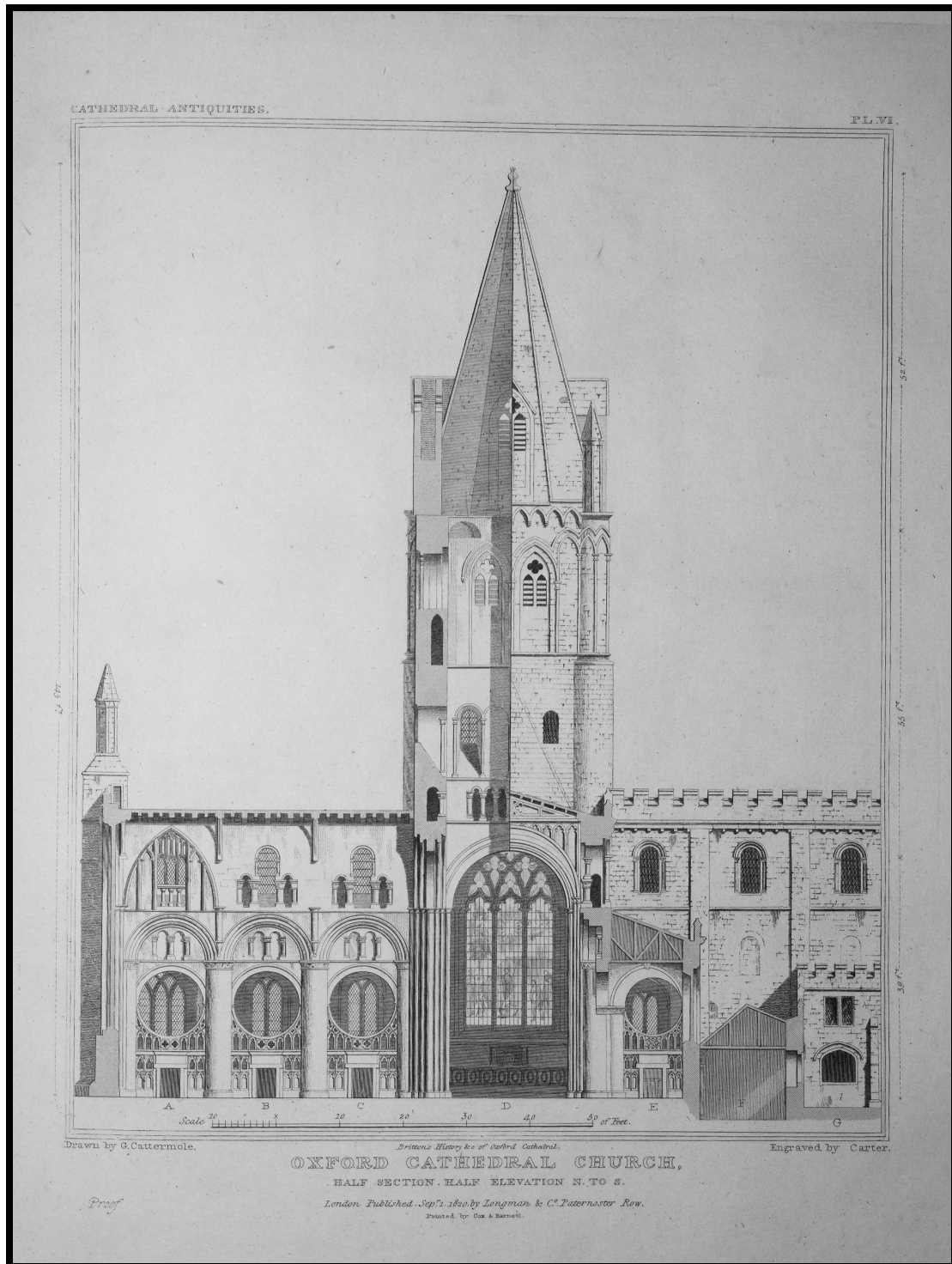


Figure 3-46 “Section of the north transept, and half of the tower and spire; and elevation of the south transept, part of the tower, and one division of the cloister....A. opening to the Latin Chapel; B. to an aisle called the Dean’s Chapel...C. south aisle of the choir; D. arch under the tower, through which are seen the alter rails and window; E. section through the south aisle of nave” (Britton 1821: 22 and plate VI).

In terms of the ‘Sodom and Gomorrah’ window, the text does not specify if the window is in the north or south aisle, it could be that Britton is being general about the window as it is in the same area of the building i.e. the nave, unlike ‘Christ Disputing

with the Doctors' which is very definitely in another area of the cathedral. Some of the illustrative plates in Britton's work show the aspects of the cathedral in detail, including the images contained within the windows. The images in the windows are not always clear, but the artist has attempted to show that a window contained more than just clear glass. For example, Plates VI (Figure 3-46) and VII depict the images on the east window [CE1] and the north window [NTN1]. Plate VII also shows heraldry in the upper lights of the window adjacent to the north window [NTN2]. Plate IX shows part of a window from the north aisle of the nave [W3], this window currently contains 'Jonah before Nineveh', but it is uncertain whether or not this window contained painted glass during the time Britton was writing. It has been suggested that the Oliver window may have been in this area of the cathedral, and although the image in this plate cannot confirm what the image in the window was, it does appear to be depicting a painted image. Figure 3-47 shows a blow-up of the window [W3] taken from plate IX of Britton's work, depicting images in the window which now contains 'Jonah'. A plan of the cathedral based on Britton's work is shown in Figure 3-48.



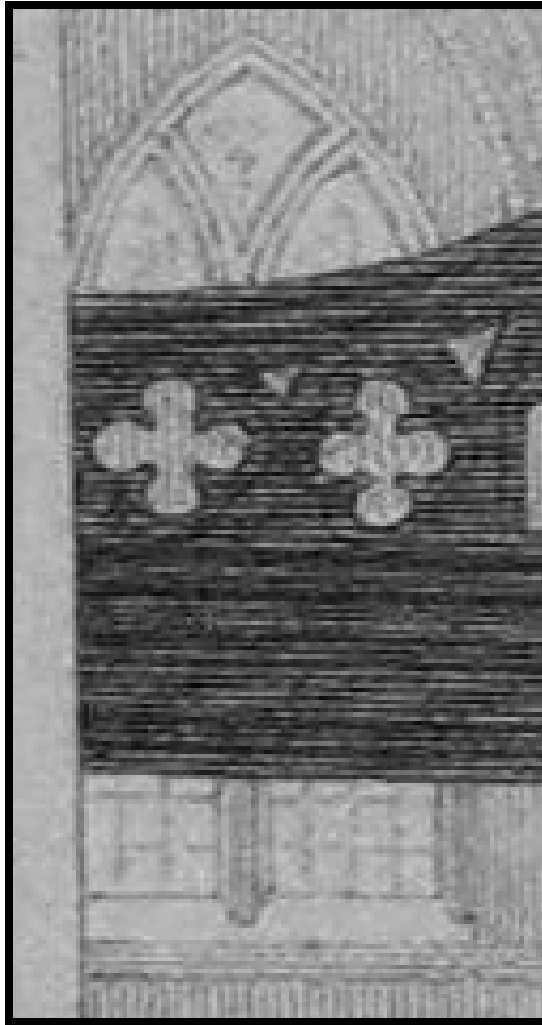


Figure 3-47 Plate IX (Britton 1821) and an enlargement of [W3] window showing undefined images present in the window, and square panes in the style of the painted windows

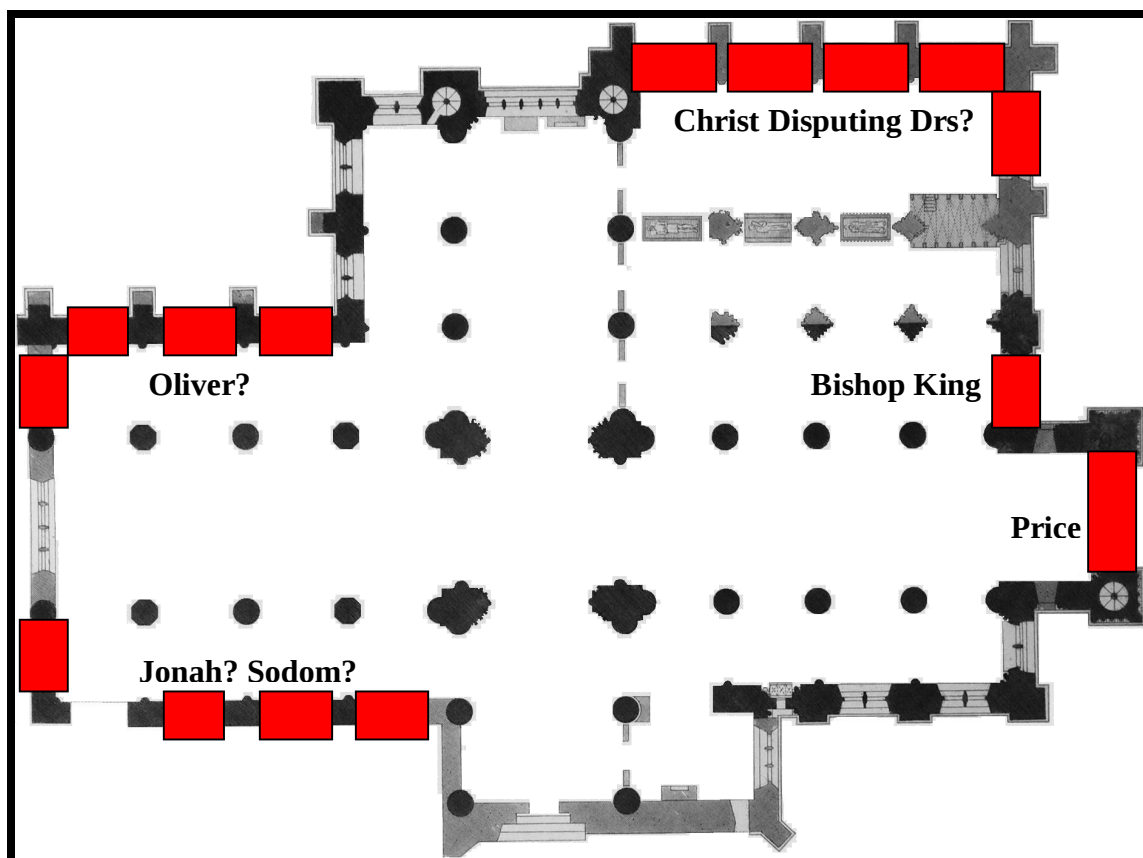


Figure 3-48 Plan of Britton cathedral

3.9.5 The Penny Magazine 1845

In an article in *The Penny Magazine* 1845 “*The stalls and fittings-up of the choir appear to have been executed about 1630, and soon afterwards most of the windows were repaired, and additional painted glass was inserted by Van Linge. Christ disputing with the Doctors in the east window of the Divinity Chapel, or Latin Chapel as it is called, which is the farthest to the north of the two chapels annexed to the choir, is by Van Linge [LC1]. The Nativity, in the great east window of the choir [CE1], is by Price, after a design by Sir James Thornhill. St. Peter conducted out of Prison by the Angel, in the window of the north aisle of the choir [NC1], is by John Oliver, and is especially curious as having been painted by him in 1700, when he was eighty-four years of age. The murder of Becket in the window of the north transept [NTN1] appears to be of great antiquity*” (Unknown 1845: 203). The start of this quote is again very reminiscent of previous authors, it mentions that ‘Christ Disputing with the Doctors’ was in the east window of the Latin Chapel, but does not mention any other Van Linge windows. This

text also moves the location of the Oliver window from the north aisle of the nave to the north aisle of the choir.

3.9.6 Trash 1849

Trash writing in 1849 is more descriptive of the window locations “*In the window above the Altar is a representation of the Nativity [CE1]....In the centre of the large north window is represented the murder of Becket, Archbishop of Canterbury [NTN1]; and in the same window, the entrance of Christ to Jerusalem [NTN1]....The window left of the above represents the Story of Jonah, executed by Van Ling in 1634 [NTN2]....The great west window [W2] is chiefly composed of fragments of stained glass, extremely ancient, representing St. Frideswide, her parents, St. Catharine, St. Lucy etc. The window left of this contains a representation of St. Peter Delivered out of Prison by the Angel [W1]; besides the principal figures, there are a number of Roman soldiers sleeping in various attitudes, admirably well drawn and executed by J. Oliver, in his eighty-fourth year, in 1700. In the window on the right of this, is the Destruction of Sodom and Gomorrah [W3]. A window in the aisle, called Bishop King’s aisle [SC1-SC4], contains a fine figure of the Bishop in his Episcopal robes, with his mitre on his head, a pastoral staff in his hand, and the remains of Osney Abbey, in the back ground, of which he was the last Abbot, and first Bishop of Oxford. This window was taken down and preserved during the usurpation, by one of the Bishop’s family, about the year 1648, and put up again at the restoration in 1660 (Trash 1849: 111-114).*

Interestingly, Trash mentions all the picture windows except ‘Christ Disputing with the Doctors’, instead, he does mention that the ‘Entry to Jerusalem’ is in the same window as the ‘Murder of Becket’, and that this is located in the north transept window. The fact that these latter two images are in the same window suggests that both are in a fragmentary state. Trash mentions the ‘Story of Jonah’, this is assumed to be ‘Jonah before Nineveh’ as that is the surviving Jonah window, but, he dates the window as 1634, whereas all other authors date the window as 1631. The author may have made a mistake, but his descriptions suggest he is walking around the cathedral and recording what he saw. Trash also mentions, what is assumed to be, the 14th century glass from the Latin Chapel as being fragmentary in the west window. Trash also makes reference to the Bishop King aisle where previously we were told by Wood (Wood quoted in Gutch

1786) that all the windows in the south aisle were donated by Dr King. This also raises some interesting questions. If all the windows in the south choir aisle were donated by the King family this suggests that all the windows in this aisle would have been picture windows. If this was the case, when the windows were threatened during the 1640s, why did the family only save the Bishop King window? Two possible answers to this could be that the Bishop King window was a depiction of the family's ancestor and therefore worth saving whereas the other windows were just scriptural. Also, the 'Bishop King' window is a very small window and therefore may have been saved over the others due to its size. It would also have been easier for the family to preserve a small heraldic window over a large scriptural window. It is worth noting, that the description of the Oliver window is almost word for word the same description as that given in Prince and Cooke (1789), the only difference being the location of the window. It may be possible that when Trash is describing the location of the Oliver window he is standing with the west window behind him (almost as if narrating to an audience facing him). He says the window to the left is the Oliver window, making it [W3], and then turns to face that window and says '*the window on the right of this*' is 'Sodom and Gomorrah', thereby making the latter window [NN3]. This latter hypothesis is extreme but may explain why windows appear to have been moved for no readily apparent reason. Figure 3-49 illustrates the layout of the Trash cathedral plan.

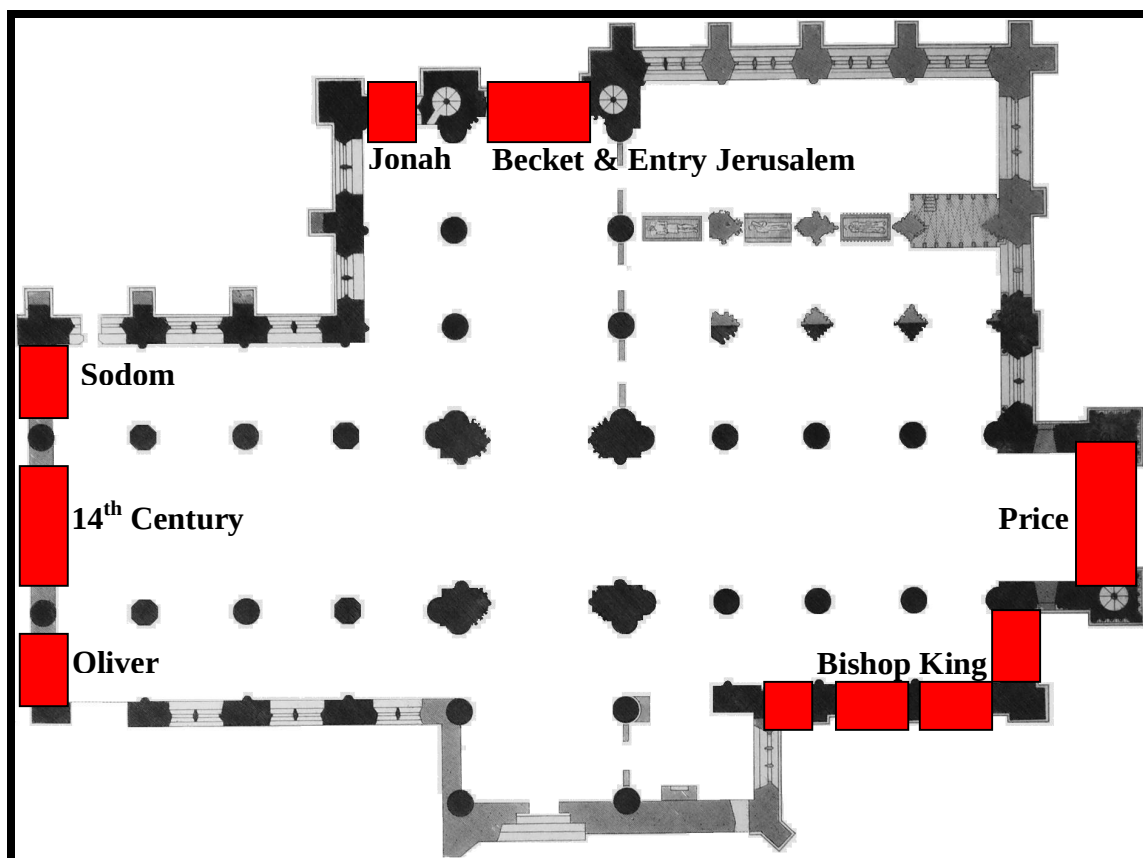


Figure 3-49 Trash plan of cathedral

3.9.7 Urban 1850

In 1850, the *Gentleman's Magazine and Historical Review* recorded that “*The known works of Abraham Van Linge are more numerous. 1631. The earliest is in the south aisle of Christ Church [W1, SN1-SN3], Oxford, representing Jonah sitting under the gourd, contemplating Nineveh. It was presented by Charles Sunibanke, D.D. Prebendary of Windsor, and is inscribed ‘Abraham van Linge fecit 1631.’ Others in the same church were executed in the years next ensuing*” (Urban 1850: 386 – 387).

“*Van Linge’s windows were replaced after the Restoration, and probably on that occasion received some repair, but are now in a state of considerable decay. The last in date is that of Christ disputing with the Doctors in the last window of St. Frideswide’s chapel [LC1], afterwards called the Divinity School. It is thus inscribed, Anno aerae Christianae MDCXL. Abraham van Linge fecit 1640*” (Urban 1850: 387). If the Jonah window which Trash refers to as being in the west aisle of the north transept is the

‘Jonah before Nineveh’, then within the space of a year the window has been moved to another location within the building.

3.9.8 Parker et al 1858

“among these interesting fragments are some of the fourteenth century, if not earlier, as the murder of St. Thomas à Becket, in the north window [NTN1]; St. Augustine, St. Blaise, and St. Martin dividing his cloak with a beggar, in the west window [W2]; a crucifixion, with the two Maries, and the emblems of the crucifixion, represented within the letters ‘IHC,’ and the Blessed Virgin, surrounded by a glory or aureole, contained in the letter M, in the east window of the Lady Chapel [LDY1]; and among those of later periods may be mentioned the figures of St. Frideswide, with her parents, St. Catherine, St. Lucy, etc, in the west window [W2]; and the portrait of Bishop King, in the south aisle of the chancel [SC1-SC4]; whilst that in the north aisle of the nave [W3, NN1-NN2], St. Peter’s release from prison, painted by Isaac Oliver when 84 years of age...A window of the north aisle of the nave, immediately opposite the door [NN3], is filled with the badges of Cardinal Wolsey, brought from the windows of the hall: these are very conspicuous, and little out of place. The end window of the west aisle of the north transept [NTN2] is a singular specimen of the style of Abraham Van Ling, 1630, with a great preponderance of green foliage. He appears to have also arranged the fragments in the great north window [NTN1], and filled up the intervals in a similar manner.

The east window [CE1] was re-glazed by a subscription among the members of the college in 1854. The painted glass was commenced by the late Henri G rente, of Paris, the most eminent artist of his day in that department of art, but he unfortunately died of cholera before much progress had been made, and the work was completed by his brother, Alfred G rente, also of Paris” (Parker et al. 1858: 20-21). The Van Linge window in the north transept aisle [NTN2] is most likely to be the ‘Jonah’ window, the description of foliage is the tree under which Jonah is sitting. Figure 3-50 shows the layout of the Parker et al cathedral.

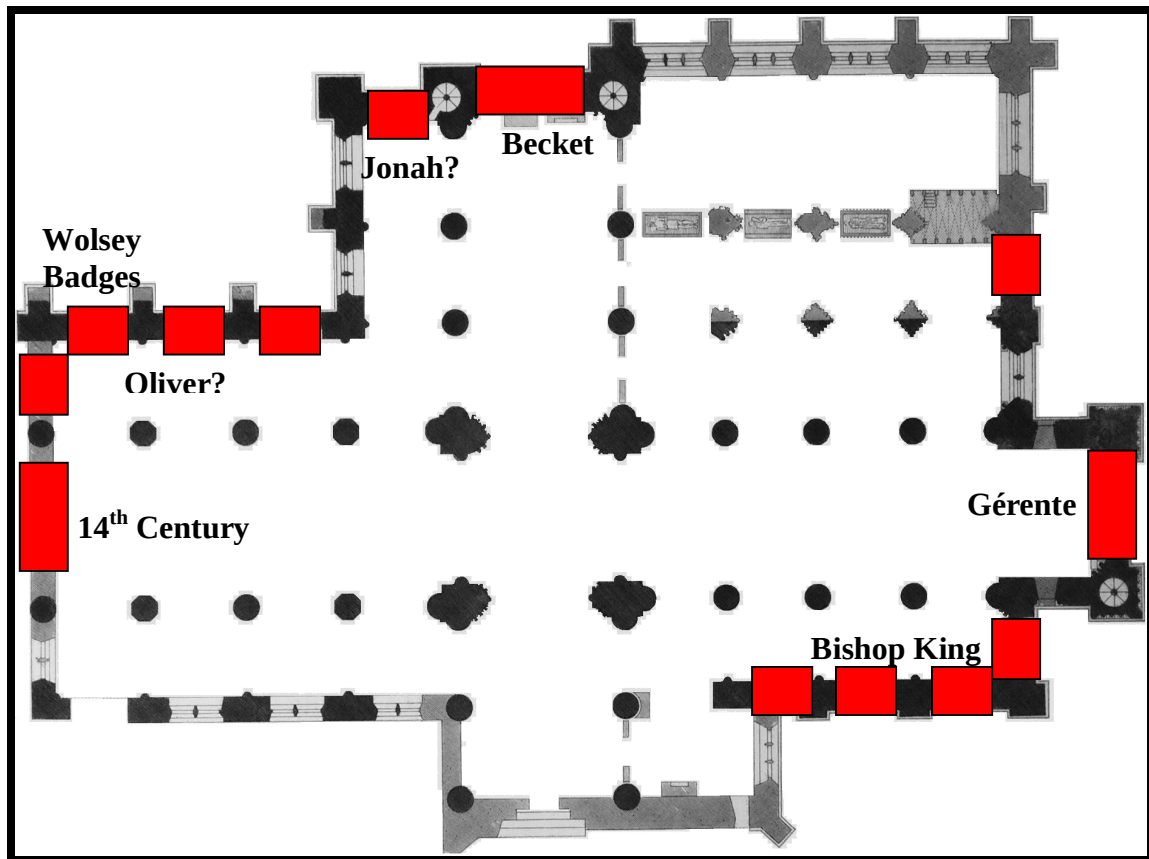


Figure 3-50 Plan of Parker et al cathedral

3.9.9 Walcott 1858

Walcott (1858) is an author who seems to have confused the locations of the different chapels within the cathedral. *“The vestry, formerly St. Lucy’s Chapel, has an exquisite window of flamboyant character...The north transept has a west aisle; on the east are the chapels of St. Frideswide and St. Mary. The former is now called the Dean’s Chapel. The east window [LC1] has stained glazing by Abraham Van Linge, representing Christ disputing with the Doctors, and is dated 1640. In the south aisle [W1, SN1-SN3] are two other stained windows by the same master – the story of Jonah, dated 1631, Sodom and Gomorrah destroyed, dated 1634; and Bishop King’s window, interesting as containing a view of Osney Abbey. In the north aisle [W3, NN1-NN3] is a window, the subject St. Peter and the Angel, painted by Isaac Oliver in 1700 at the age of eighty-four. The Lady Chapel is now called the Latin Chapel...and sometimes the Divinity Chapel....The former ugly east window [CE1], designed by Sir James Thornhill, and stained by Price in 1696, was in 1854 replaced by glazing designed by*

Hudson and executed by Alfred Gerente. It contains the events of our Lord's life" (Walcott 1858: 74-75). Walcott appears to mention at least 4 names for what is now the Latin Chapel. This confusion suggests that Walcott may have been referring to earlier texts rather than visiting the building himself. Walcott also changes the location of the 'Jonah' window to the south aisle, whereas Parker et al (1858) have this next to the north transept window in the same year of publication, this would support the idea that he may be referring to earlier texts. The contradiction to this idea comes in the way Walcott describes the old east window as ugly, but this could just be a reaction to the tastes and fashions of the time.

3.9.10 King 1862

In 1862 King wrote "*The original west end seems to have been worked up again by Wolsey. At any rate, a Norman string is cut through by the west window [W2], which is early Decorated (geometrical), of four lights. A smaller window, of similar character, is inserted at the end of each aisle [W1, W3]. The stained glass in all of these is interesting, and should be examined. That in the west window is principally made up of ancient fragments belonging to the fourteenth and fifteenth centuries. The window in the south aisle [W1], dated 1631, represents the destruction of Sodom and Gomorrah, which appear as modern Dutch towns. It is by Abraham Van Linge, who filled many windows in the cathedral with stained glass between the years 1630 and 1640. Some of these were destroyed during the Rebellion; but others were taken down and preserved. The window in the north aisle [W3], representing St. Peter's release from Prison, is dated 1700, and is the work of Isaac Oliver, nephew of the better known miniature painters, Peter and Isaac Oliver. The artist was aged 84 when he executed this window, which was his own gift to the college. The window adjoining [NN3] is filled with the badges of Cardinal Wolsey, brought here from the hall, and, although interesting, not altogether in place*" (King 1862: 10). This text again places 14th century fragments in the west window, 'Sodom and Gomorrah' in the south aisle, and the Oliver window in the north aisle. Above the Dean's entrance was located the badges of Cardinal Wolsey. The way in which this piece is written is again reminiscent of earlier writers; in fact it is very similar to the work of Parker et al (1858).

“The east window [CE1], which is early Decorated, was filled with stained glass by a subscription among the members of the College in 1854, to commemorate the third centenary of its establishment. The glass, which represents the principal events in the life of our Saviour, was the work of the brothers Henri and Alfred G rente, - the first of whom died before the window was completed” (King 1862: 15).

Then, in relation to the north transept, *“The large five-light window at the end of this transept [NTN1] contains a painting by Van Linge, representing the entry of Christ into Jerusalem. Various portions of earlier glass, however, have been inserted in the middle of the picture. In the centre light is the murder of Becket, dating early in the fourteenth century, and well deserving notice for the excellent example of armour it affords. The chain-mail of the knights, their ‘genouilli res,’ or knee-caps, and the form of their swords, should be remarked. The bearings of Fitzurse and Le Bret are conspicuous on their shields. The Archbishop kneels before the altar of St. Benedict, beside which stands his cross-bearer, the Saxon monk Grim, whose arm is wounded by the sword of Fitzurse. The figures are placed on a diapered ground of red and blue. The window at the end of the transept aisle [NTN2], also by Van Linge, represents the city of Nineveh, with Jonah sitting under the shadow of the gourd” (King 1862: 17-18).*

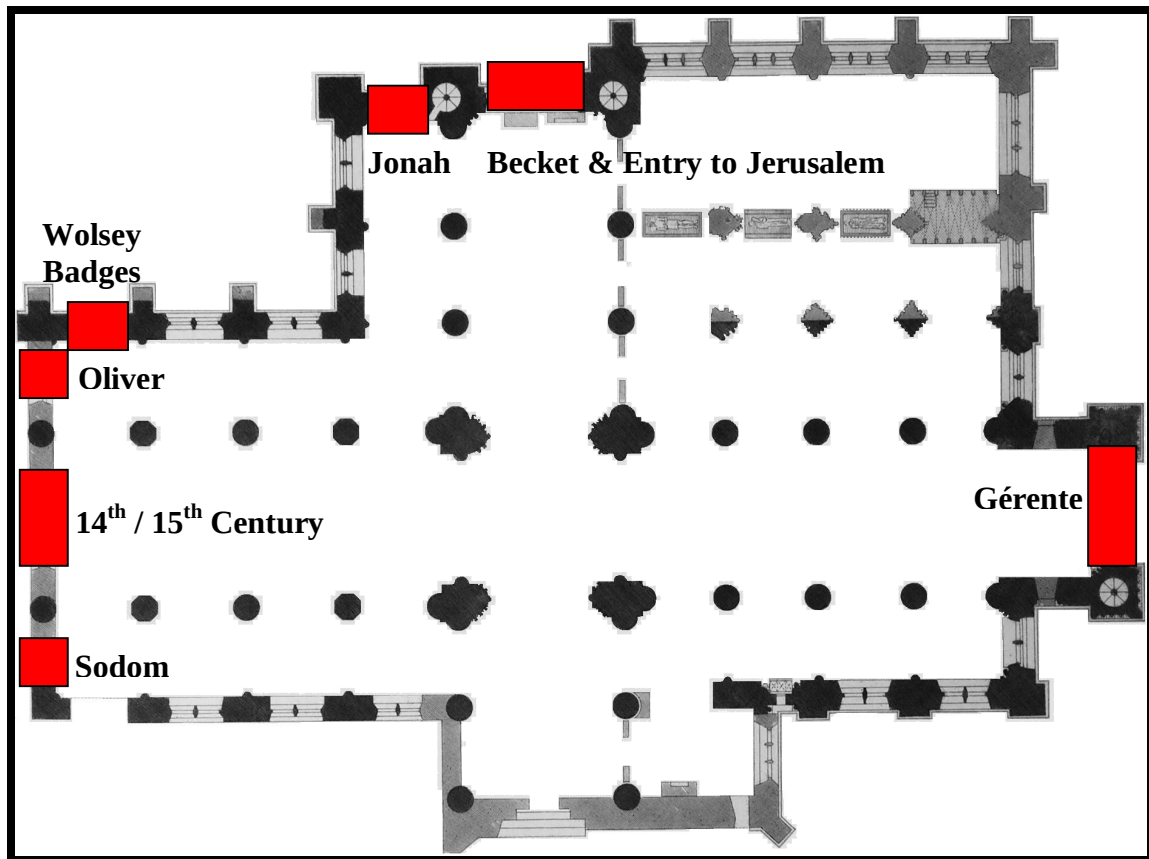


Figure 3-51 Plan of King's cathedral

King also mentions the Bishop King window and that it was probably painted by Van Linge. By 1862 the Van Linge image of 'Christ Disputing with the Doctors' has been removed from the Latin Chapel and replaced with the existing Burn-Jones window "*An entirely new east window [LC1], with beautiful, but strangely incongruous Venetian tracery and stained-glass, has been inserted as a memorial of Dr. Bull, Canon of Christ Church, who died in 1859*" (King 1862: 26). Figure 3-51 shows the cathedral as King describes the plan.

3.9.11 Thompson 1899

Dean Liddell began the renovations to the cathedral in 1852, and these were later completed during the 1870s (Thompson 1899). "*The plain two-light windows which Brian Duppa had inserted throughout the church, and had filled with Van Ling's glass, were removed, and somewhat commonplace Perpendicular windows took their place. One only of these curious windows remains. It was spared in compliance with a general request of members of the House, and may be seen at the west end of the north aisle of*

the nave [W3]. It represents Jonah under the gourd, and the city of Nineveh in the distance. The east window, then of Decorated tracery, and filled with gaudy French glass recently given in commemoration of the tercentenary of the foundation of the College, made way for a charming reconstruction of the eastern end in accordance with indications of earlier work discovered by the architect [CE1]. Portions of the French glass may still be seen distributed among the clerestory lights of the south transept...At the west end of the nave an additional bay was built, replacing one of the three destroyed by Wolsey” (Thompson 1899: 157-158). The addition of this extra bay saw the removal of the west window, and the cathedral and its windows are largely as they appear today (Figure 3-52).

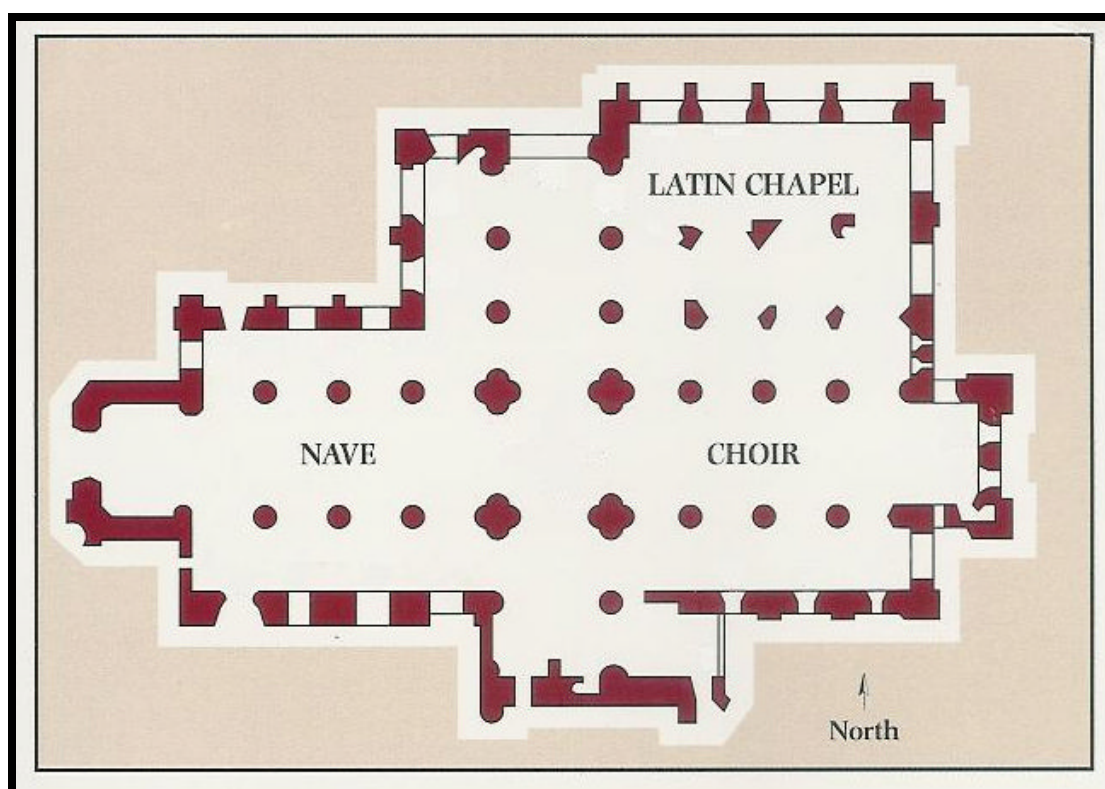


Figure 3-52 Plan of cathedral today

3.10 Summary of the Van Linge window history

The Van Linge window scheme in Christ Church cathedral would have been one of the biggest window schemes in the country. The large number of windows involved would have made this scheme unique (Power & Shortland 2007). The cathedral provided the space for Dean Brian Duppa to express the artistic views of Laud and

others by patronising the Van Linges and encouraging them to fill the cathedral with their work. During the years surrounding the Civil War, religious stained glass was a target for iconoclastic acts. The painted windows of Christ Church were seen as papist and idolatrous and were removed for their own safety (Urban 1850). Based on the information from 18th and 19th century authors, around 1660, some of the windows were re-instated, and five Van Linge windows were returned to the building. Three of these windows were ‘Jonah before Nineveh’, ‘Bishop King’, and the destruction of ‘Sodom and Gomorrah’.

3.10.1 Bishop King

‘Bishop King’ was removed from the cathedral and stored by the King Family until the Restoration, when the window was returned to the building. The subsequent survival of this window during later renovations is probably due to the small size of the window and its relatively insignificant location within the building.

3.10.2 Jonah before Nineveh

‘Jonah before Nineveh’ also survives in the cathedral today. This window appears to have been moved around the building at various points in its history, but no explanation for this is apparent. The ‘Jonah’ window is first located in [LCY1] as part of the Van Linge scheme, by 1786 it has been moved to a location within the south aisle of the nave. In 1821 ‘Jonah’ is again mentioned in the south nave aisle (Britton 1821), but, by 1849, the window has been moved to north end of the north transept aisle (Trash 1849). Urban (1850) records the window as being back in the south nave aisle again, but Parker et al (1858) put ‘Jonah’ back in the north transept aisle. Walcott also writing in 1858 puts the ‘Jonah’ window in the south nave aisle, whereas King (1862) puts the window in the north transept aisle. It is likely that the window was moved from the south nave aisle to the north transept aisle sometime between 1821 and 1849, and that later authors who claim the window is in the south nave aisle are, in fact, referring to earlier texts rather than visiting the cathedral themselves. If all the authors are correct, then it would mean that the window was moved between the two locations 4 times in the space of 12 years; this seems unlikely due to the expense and impracticality that

would have been involved. ‘Jonah before Nineveh’ was then saved from destruction by popular demand of the members of the house in the 1870s (Thompson 1899). Table 3-4 summarises the different locations of the Jonah window based on 18th and 19th century texts.

Date	Author	Location
1630s	Van Linge Scheme	LCY1
1786	Gutch	South Aisle
1821	Britton	South Aisle
1849	Trash	NTN2
1850	Urban	South Aisle
1858	Parker et al	NTN2
1858	Walcott	South Aisle
1862	King	NTN2
1899	Thompson	W3

Table 3-4 Table of the different locations for the ‘Jonah’ window

3.10.3 Sodom and Gomorrah

‘Sodom and Gomorrah’ no longer survives as a complete window in the cathedral, but fragments of this can be seen in the upper lights and the clerestory lights of windows in the north transept. ‘Sodom and Gomorrah’ would originally have been located [NTW2] as part of the Van Linge scheme, it was then moved to the north nave aisle by 1786, but by 1821 the window appears to have been moved to the south nave aisle, and then in 1849 the window is back in the north nave aisle. The next mention of the ‘Sodom’ window is in 1858 when the window is placed in the south nave aisle, and King (1862) also places this window in the south nave aisle. This poses a small dilemma, again, as with the ‘Jonah’ window, ‘Sodom’ is being moved back and forth between two locations (although the exact window in the aisles in question is not always known). It is likely that at least one author is copying the work of an earlier author. If as was suggested earlier Britton (1821) got his aisles the wrong way round, then it could be that ‘Sodom’ was actually in the north nave aisle when he was writing, if this was the case then it would have implications as to where ‘Jonah’ and other windows were located. Alternatively, Britton is correct in his placement of the ‘Sodom’ window, and Trash writing in 1849 was copying an earlier author. The latter idea is more likely to be the case, as mentioned earlier, aspects of Trash’s text are similar to the writings of

Prince and Cooke (1789), although Prince and Cooke do not mention any of the Van Linge windows. Table 3-5 summarises the different locations for the ‘Sodom and Gomorrah’ window based on 18th and 19th century texts.

Date	Author	Location
1630s	Van Linge Scheme	NTW2
1786	Gutch	North Aisle
1821	Britton	South Aisle
1849	Trash	W3
1858	Walcott	W1

Table 3-5 Table of different locations for the ‘Sodom and Gomorrah’ window

3.10.4 Other windows which survived the Restoration

The other two windows which are supposed to have survived the restoration were ‘Christ Disputing with the Doctors’ and the ‘Entry to Jerusalem’, this latter window is quoted in the literature but this author feels that it may also have been fragments from the ‘Ressurrection’. Fragments with faces of men thought to be from the ‘Christ Disputing with the Doctors’ window can be seen today in the clerestory windows of the north transept. Where this window is mentioned in Victorian writings it is placed in the Latin Chapel. In most cases it is specified as being the east window of this chapel. But some authors do not mention the window at all. For example, the window is present in 1786, 1821, 1845, 1850, 1858 (Walcott), but it is not mentioned at all by authors published in 1849, 1858 (Parker et al) and 1862. This may mean that the window was removed between 1845 and 1849 and that both Urban (1850) and Walcott (1858) are copying earlier writers, alternatively the window was present until Liddell’s renovations of the 1850s and is then removed and that Trash (1849) for some reason misses this window from his narrative. The complication to the narrative of this window is that where Trash (1849) and King (1862) do not mention the presence of ‘Christ Disputing with the Doctors’, they instead mention the presence of the fragmentary ‘Entry to Jerusalem’ in the north transept window. Even Parker et al (1858) who do not specifically mention the ‘Entry to Jerusalem’ mention Van Linge work in the north transept window and that the image has a certain amount of foliage present. No other authors mention an ‘Entry to Jerusalem’ window. Britton (1821) has a representation of the north window in one of his plates, but it is not clear from the image what the

window represented, and Britton does not describe this window. It is apparent that a fifth pictorial Van Linge window survived, at least in a fragmentary state, but it is not clear what this window was. Table 3-6 outlines the locations of ‘Christ disputing with the Doctors’ and the ‘Entry to Jerusalem’ windows.

Date	Author	Window	Location
1630s	Van Linge Scheme	Christ Disp. Drs. Entry Jerusalem	LC1 ST1
1786	Gutch	Christ Disp. Drs.	LC1
1821	Britton	Christ Disp. Drs.	Latin Chapel
1845	The Penny Magazine	Christ Disp. Drs.	LC1
1849	Trash	Entry Jerusalem	NTN1
1850	Urban	Christ Disp. Drs.	LC1
1858	Walcott	Christ Disp. Drs.	LC1
1862	King	Entry Jerusalem	NTN1

Table 3-6 Table of different locations for ‘Christ Disputing with the Doctors’ and the ‘Entry to Jerusalem’ windows

There is much debate over the latter two windows, because some authors refer to one and some refer to the other and neither window is mentioned in the same text, suggesting that neither window was present at the same time. Fragments from both windows have been identified at Christ Church, but again, not enough to provide a complete window. When the ‘Entry to Jerusalem’ is mentioned as being present in the cathedral, it is always referred to as being in a fragmentary state, suggesting that this particular window did not survive the Civil War intact, but enough of the window remained to warrant its return to the building.

3.10.5 Price and Gérente

In 1696 William Price painted a Nativity for the east window (Figure 3-53), and this window stayed in place until its removal in 1854, this was replaced by glazing designed by Hudson and created by Alfred Gérente (Walcott 1858). This window was given in commemoration of the tercentenary of the foundation of the college and remained in place until the 1870s (Thompson 1899).



Figure 3-53 Print of the Price east window (courtesy of M. Power 2010)

3.10.6 Oliver

A window painted by J. Oliver in 1700 was situated in one of the nave aisles of the cathedral, and again, the location of this window is debated. All of the authors, previously mentioned as having described the windows, place the Oliver window somewhere in the north nave aisle, except for Trash (1849) who places the window in the south nave aisle. There is no apparent reason why this window would have been

moved, and it is more likely that Trash was either confused in his description of the location, or was copying an earlier unknown author who had also made a mistake.

3.10.7 Liddell Renovations

During the 1870s Dean Liddell renovated the cathedral and changed a lot of the interior of the building, he removed all of the painted windows except one, which, as mentioned previously, was spared in compliance with a general request from the members of the house (Thompson 1899). At this time the east window of the cathedral was again changed to the existing Clayton and Bell Rose window and two lights. Surviving fragments of glass from the Gérente window were placed in the tower lights (Thompson 1899), where they can be seen today.



Figure 3-54 Van Linge fragments in north transept (image courtesy of J. Rogers 2010)

3.11 1630 After Reconstruction

On entering the cathedral, one would have instantly been greeted by bright, colourful windows, containing biblical stories. These windows would have appeared even more vivid because of the dark wood panelling throughout the building. The first window on the left would have been the ‘Nativity’, Christ’s entry to the world, reflecting entry to the church. The next most apparent windows were the stories of ‘Jacob and Isaac’ and ‘Abraham and Isaac’, reminding worshippers of the sacrifices to

be made in the name of God. On the right of the entrance was the story of Moses reflecting the message of the 'Nativity'. The vividly painted images imparting the messages of the Old Testament would have ensured that worshippers knew why they were there. The four main windows of the cathedral displayed four of the important aspects of Christ's life: 'Nativity', 'Entry to Jerusalem', 'Resurrection', and 'Pentecost'. The east end of the south choir aisle would have been a dark and gloomy corner, depicting the 'Crucifixion', and 'the Tomb', this would have been in stark contrast to the bright and lively image of the 'Resurrection' in the main east window of the choir. The further into the cathedral worshippers went, the more of the New Testament was revealed. The windows themselves would have brought to life the biblical stories; this would have been especially useful for the illiterate members of the congregation. Assuming the windows would have contained several aspects of each story, similar to the windows in Queen's or University College Chapels, then each window would have provided a message. The dark surroundings created by the wood panelling, would have meant that each message would have been reinforced in the minds of the worshippers as the windows would have stood out. The lifelike paintings would have animated the lesson being preached. The whole scheme would have had a very powerful effect on the gathered assembly, and this would have added to the Puritan argument of the power contained in the images.

3.12 Results

Although some of the 9000 fragments of glass in the collection at Christ Church have been attributed to artist and periods of history on stylistic grounds, this thesis sought to discover whether any of these fragments could be differentiated on compositional grounds. 91 samples of glass were chosen from the collection, and analysed using a range archaeological and forensic techniques. The glass was first characterised and then attempts were made to provenance the glass. Table 3-7 lists the samples taken from the collection of fragments at Christ Church. The samples have been colour-coded based on an art-historic analysis of the samples. The samples were chosen from as wide a range as possible to reflect Medieval, 17th Century, and Victorian glass.

Sample No.	Art-historic Date	Colour	Window
CCOX01	Victorian	Colourless	
CCOX02		Colourless	
CCOX03		Colourless	
CCOX04		Colourless	
CCOX05		Colourless	
CCOX06	Van Linge (1630s)	Colourless	
CCOX07		Colourless	
CCOX08	Van Linge (1630s)	Colourless	
CCOX09	Van Linge (1630s)	Colourless	
CCOX10	Van Linge (1630s)	Colourless	
CCOX11	Van Linge (1630s)	Colourless	
CCOX12	? Price	Colourless	
CCOX13		Colourless	
CCOX14		Colourless	
CCOX15	? Van Linge	Colourless	
CCOX16		Colourless	
CCOX17	? Van Linge	Colourless	
CCOX18	? Van Linge	Colourless	
CCOX19	? Van Linge	Colourless	
CCOX20		Colourless	
CCOX21		Colourless	
CCOX22	? Van Linge/Price	Colourless	
CCOX23	Victorian	Colourless	
CCOX24	Victorian	Colourless	
CCOX25	Victorian	Red Flash	
CCOX27	Victorian	Red Flash	
CCOX28	Victorian	Yellow	
CCOX29	Victorian	Green	
CCOX30	? Victorian	Red Flash	
CCOX31	Victorian	Red Flash	
CCOX32	? Victorian	Purple	

CCOX33		Dark Blue	
CCOX34	? Van Linge	Colourless	
CCOX35		Colourless	
CCOX36	? Van Linge	Colourless	
CCOX37	Van Linge (1630s)	Colourless	
CCOX38		Colourless	
CCOX39	? Van Linge	Colourless	
CCOX40	? Van Linge	Colourless	
CCOX41	? Van Linge	Colourless	
CCOX42	Van Linge (1630s)	Colourless	
CCOX43	Van Linge (1630s)	Colourless	
CCOX44	Price (1696)	Colourless	
CCOX45	Van Linge (1630s)	Colourless	
CCOX46	Van Linge (1630s)	Colourless	
CCOX47	Van Linge (1630s)	Colourless	
CCOX48	Van Linge (1630s)	Colourless	
CCOX49	Van Linge (1630s)	Colourless	
CCOX50	? Price	Colourless	
CCOX51	? Price	Colourless	
CCOX52	Van Linge (1630s)	Colourless	
CCOX53		Colourless	
CCOX54		Colourless	
CCOX55	Van Linge (1630s)	Colourless	
CCOX56	? Price	Colourless	
CCOX57	Price 1696	Colourless	
CCOX58	? Van Linge	Colourless	
CCOX59		Colourless	
CCOX60	? Van Linge	Colourless	
CCOX61		Colourless	
CCOX62		Colourless	
CCOX63	Van Linge (1630s)	Colourless	
CCOX101	Van Linge (1630s)	Colourless	Arms of King Family
CCOX102	Medieval	Colourless	Latin Chapel
CCOX103	Victorian	Colourless	
CCOX104	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX105	Van Linge (1630s)	Colourless	Christ disputing Drs
CCOX106	Price 1696	Colourless	Wolsey Crest
CCOX107	Price 1696	Colourless	
CCOX108	Van Linge (1630s)	Colourless	Arms of Burton
CCOX109	Van Linge (1630s)	Colourless	Arms of Thomas
CCOX110	Price 1696	Colourless	Arms of Birch
CCOX111	Price 1696	Colourless	Nativity
CCOX112	Price 1696	Colourless	
CCOX113	Price 1696	Colourless	
CCOX114		Colourless	
CCOX115		Colourless	
CCOX116	Price 1696	Colourless	
CCOX117	Price 1696	Colourless	
CCOX118	Price 1696	Colourless	
CCOX119	Price 1696	Colourless	
CCOX120	Price 1696	Colourless	
CCOX121	? Van Linge	Dark Blue	
CCOX122	? Price/Oliver	Colourless	
CCOX123	? Van Linge/Victorian	Light Blue	
CCOX124		Colourless	

CCOX125	Victorian	Purple	
CCOX126	Price 1696	Colourless	
CCOX127	Price 1696	Colourless	
CCOX128	Victorian	Red Flash	
CCOX129	Price 1696	Colourless	Nativity

Table 3-7 Table of samples from Christ Church showing sample number, date, colour and location if known. The sample numbers are in the colour that defines a particular group: Price, Victorian, Van Linge, Other

All of the glass analysed by elemental analysis can be clearly assigned to a specific group which in most cases relates to a specific art-historic period; the glass of the 17th century can be further sub-divided between the artists operating at the time. The fragments of glass in the collection at Christ Church, mainly housed in the Bethel, are thought to have come from (amongst others) three Van Linge windows ('Christ Disputing with the Doctors', 'Entry to Jerusalem', and 'Sodom and Gomorrah'). Also included in the collection are fragments from the Price window and the Oliver window, some medieval fragments and some Victorian fragments. The analyses of the major and minor elements clearly show that the glass analysed falls into these groups (Figure 3-55), with the exception of the Oliver window. None of the fragments chosen could definitely be ascribed to Oliver based on a stylistic/art-historic basis. Equally so, the three samples which fall into the 'other' group because they appear to form a distinct group on their own, are all colourless samples and without further data, cannot be ascribed to a specific artist or art-historic period. It would be convenient to say that these three samples were representative of the Oliver window, but this is impossible without further information on the glass. Alternatively if samples of glass which can definitely be assigned stylistically to Oliver can be found within the collection at Christ Church, then these could be analysed and provide a basis for comparison with the three unknown samples. Oliver was an artist to whom only one window in the cathedral was attributed and like Price he is said to have restored some of the earlier works.

Amongst the fragments of glass analysed were several pieces taken from heraldic coats of arms, these were also painted during the 17th century, and often filled the tracery lights of the windows. From the analyses performed (SEM-WDS and LA-ICP-MS) it has been possible to tell 'who' painted the arms of which benefactor, for example, Wolsey's Crest and the arms of the Birch Family were painted by Price, whereas the arms of Robert Burton and the arms of the Thomas Family were painted by the Van Linges. This corresponds with the art-historical evidence for the style of

painting and historical descriptions of which coats of arms were associated with specific windows.

3.12.1 SEM-WDS

91 samples of glass from the collection of fragments from Christ Church Cathedral, Oxford were analysed using Scanning Electron Microscopy – Wavelength Dispersive Spectrometry (SEM-WDS). The results showed that the glass could be characterised into four main groups, and that these groups could be attributed to specific artists or periods of history. The four groups are Price, Van Linge, Victorian, and Other. Some samples which had been assigned on art-historic grounds to a specific group were in fact compositionally assigned to a different group.

Most of the samples form two groups, these have both been identified art-historically as being 17th century glass, and have been attributed to the glass painters William Price (senior) and the Van Linges. Both groups of glass are High Lime, Low Alkali (HLLA) glasses, and this is a common type of glass found during the 17th century (Dungworth 2008: pers. comm.). HLLA is recognisable by its high CaO content (>15 wt%) and low alkali content ($\text{Na}_2\text{O} + \text{K}_2\text{O} < 10$ wt%) (Dungworth et al. 2006). The first set which has been attributed to the work of Price, all group together consistently, and these can be characterised by low Na_2O 0.83-1.05 wt%, MgO around 2.2 wt%, and high CaO 22.34-24.63 wt% contents (Table 3-8).

Sample	Na_2O	MgO	CaO
CCOX44	0.83	1.79	23.08
CCOX57	0.94	1.92	23.65
CCOX106	0.95	1.90	23.62
CCOX107	0.87	1.81	23.47
CCOX110	1.01	2.07	23.41
CCOX111	0.85	1.78	23.12
CCOX113	0.94	1.98	24.16
CCOX116	0.95	1.99	22.72
CCOX117	0.92	1.99	23.93
CCOX118	0.95	2.04	23.28
CCOX119	0.94	1.98	24.10
CCOX120	1.02	2.15	23.25
CCOX126	0.93	1.91	22.81
CCOX127	0.92	1.93	23.89

CCOX129	0.93	1.87	24.19
CCOX122	0.89	1.84	23.40
CCOX12	0.94	1.92	23.60
CCOX50	1.05	2.03	22.84
CCOX51	1.00	2.04	22.91
CCOX56	0.89	1.84	22.51
CCOX07	1.00	2.00	23.40
CCOX13	0.95	1.84	23.14
CCOX35	0.90	1.89	23.65
CCOX38	1.02	2.06	23.10
CCOX54	0.95	1.93	24.16
CCOX59	0.90	1.94	24.40
CCOX61	1.04	2.07	23.56
CCOX62	0.99	1.97	23.61
CCOX115	1.02	2.03	23.00
CCOX45	1.01	2.12	23.18
CCOX15	0.92	1.92	22.34
CCOX58	0.93	1.95	23.87
CCOX60	0.91	1.89	24.63
CCOX22	1.01	2.06	23.57

Table 3-8 Characterisation of Price samples

The Price samples begin to disperse when the SO_3 and Fe_2O_3 contents are plotted. The second set, the work of the Van Linges, have a tight core to the group, which is characterised by Na_2O 2.9-3.8 wt%, Al_2O_3 2.8-3.3 wt%, K_2O 3.5-5.2 wt% and CaO 19.5-21.0 wt% (Table 3-9). The rest of the Van Linge samples are quite dispersed outliers. Of the van Linge samples, four were of coloured glass (CCOX33, CCOX121, CCOX124, CCOX 32); two blue glasses, one green glass and one purple glass. One of the blue glasses was flashed with white glass, but it was the bulk of the coloured glass which was analysed. All four of the coloured samples have higher K_2O (>6.08 wt%) than the colourless HLLA glasses, along with lower Na_2O (<1.24 wt%) contents. The exception to this is CCOX30, where the sample is flashed dark red, but the colourless glass was analysed; in this instance, this sample also has a higher K_2O (7.71 wt%) and lower Na_2O (0.96 wt%) content. Although the coloured samples do have some similarities with each other, they do not group together tightly consistently and often form a dispersed group. Both of the blue samples are coloured with cobalt, the green sample uses copper, and the purple glass is coloured with manganese. Figure 3-55 shows the tight groupings of the 17th century glass compared to the Victorian and Other samples.

Sample	Na ₂ O	Al ₂ O ₃	K ₂ O	CaO
CCOX06	3.24	3.04	4.51	19.90
CCOX08	3.38	3.05	4.28	20.57
CCOX09	3.48	3.14	3.99	19.68
CCOX10	3.42	2.97	4.22	20.36
CCOX11	3.48	3.17	4.00	19.64
CCOX37	3.50	3.25	4.02	19.75
CCOX42	3.51	3.17	3.85	19.53
CCOX43	3.27	3.07	4.08	20.08
CCOX46	3.38	3.14	4.11	19.91
CCOX47	2.55	4.48	5.03	21.08
CCOX48	3.20	3.01	4.15	19.99
CCOX49	2.19	4.18	4.81	23.08
CCOX52	3.37	3.20	4.34	20.81
CCOX55	2.99	3.22	5.14	19.93
CCOX63	3.75	2.94	3.64	20.50
CCOX101	3.45	3.29	4.04	19.62
CCOX104	3.61	2.87	3.75	20.04
CCOX105	3.23	2.99	3.97	19.85
CCOX108	3.69	2.92	3.58	20.09
CCOX109	3.57	3.17	3.95	20.89
CCOX17	2.49	4.24	5.33	21.17
CCOX18	4.52	4.71	4.02	17.84
CCOX19	4.54	4.58	3.90	17.59
CCOX34	3.28	3.01	5.10	20.83
CCOX36	3.60	2.95	3.72	19.87
CCOX39	3.09	2.83	4.70	20.53
CCOX40	3.79	2.90	3.54	20.19
CCOX41	3.38	2.98	4.24	20.59
CCOX33	0.99	2.98	6.99	22.33
CCOX121	1.24	2.91	6.64	21.75
CCOX23	2.23	2.24	4.23	22.72
CCOX24	2.10	2.44	4.15	22.74
CCOX30	0.96	3.11	7.71	24.03
CCOX32	0.46	4.14	10.67	18.32
CCOX04	4.12	4.40	3.33	20.21
CCOX14	3.44	3.07	4.03	19.67
CCOX16	3.58	3.08	4.11	20.96
CCOX20	3.71	2.11	2.97	21.19
CCOX21	3.69	2.20	3.09	21.55
CCOX53	2.23	4.18	5.76	21.36
CCOX114	4.51	2.69	3.28	18.60
CCOX124	0.69	1.32	6.08	21.64

Table 3-9 Characterisation of Van Linge samples, including four coloured samples

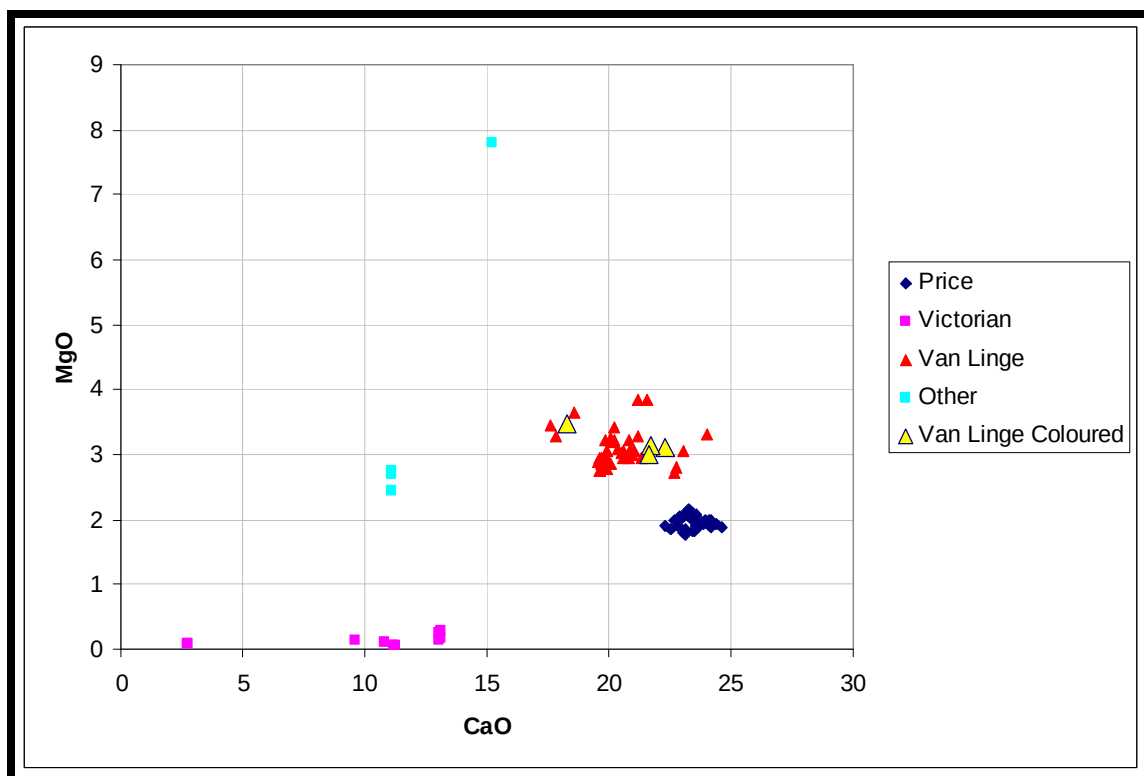


Figure 3-55 SEM-WDS plot of MgO against CaO (wt%) showing the tight groupings of the 17th century samples

The samples art-historically described as Victorian all form a relatively dispersed group, in general they can be characterised by very low MgO <0.3 wt%, 10-14.2 Wt % Na₂O, <1.7 wt% K₂O and 9.6-13.2 wt% CaO (Table 3-10). One sample in this group falls outside of these ranges, CCOX123 has a low Na₂O 5.66 wt%, very high K₂O 12.91 wt%, low MgO 0.08 wt%, and very low CaO 2.78 wt%. This sample is light blue glass which appears to have been enamelled black, and it also has noticeably different amounts of MnO (0.04 wt%), CuO (2.82 wt%), and PbO (4.27 wt%), compared to the other samples. The light blue colour of the glass can be explained by the copper content of the sample. CCOX123 is an unusual glass, it has some similarities with the medieval sample such as high potassium levels, but in many cases is an outlier to the Victorian samples.

Sample	Na ₂ O	MgO	K ₂ O	CaO
CCOX25	12.86	0.07	1.18	11.22
CCOX27	12.73	0.07	1.24	11.28
CCOX31	11.83	0.17	0.46	13.15
CCOX103	12.14	0.28	0.36	13.10
CCOX125	10.00	0.10	3.84	10.80
CCOX128	11.69	0.15	0.47	13.05

CCOX01	11.45	0.25	0.32	13.08
CCOX123	5.66	0.08	12.91	2.78
CCOX28	11.11	0.11	0.15	10.80
CCOX29	14.18	0.13	1.65	9.60

Table 3-10 Characterisation of the Victorian samples

The group ‘Other’ can be further subdivided into two sets; the first of these is one sample which is of medieval date and has a standard composition for medieval glass. This particular sample can be characterised by its high MgO 7.8 wt%, high K₂O 12.4 wt%, low Na₂O 2.3 wt% and CaO 15.2 wt% (Table 3-11).

Sample	Na ₂ O	MgO	K ₂ O	CaO
CCOX102	2.34	7.79	12.44	15.24

Table 3-11 Characterisation of the Medieval sample

The second set is a group of three samples, characterised by 2.4-2.7 wt% MgO, 8.8-9.1 wt% Na₂O, 5.1-5.2 wt% K₂O and 11.1 wt% CaO (Table 3-12). These samples appear to be of a mixed alkali composition i.e. the combined alkali contents equal c.15 wt% but neither one nor the other is particularly high or low. These latter three samples are all of colourless glass, and unknown origin i.e. they could not be attributed to a general group based on visual observations alone. It was decided that due to the small numbers of samples in these two subsets i.e. one and three, and the uncertainty of the origins of these glasses, that these should be classed as one group of ‘other’ samples.

Sample	Na ₂ O	MgO	K ₂ O	CaO
CCOX02	9.12	2.43	5.15	11.14
CCOX03	8.77	2.69	5.10	11.14
CCOX05	8.77	2.74	5.15	11.12

Table 3-12 Characterisation of the ‘Other’ samples

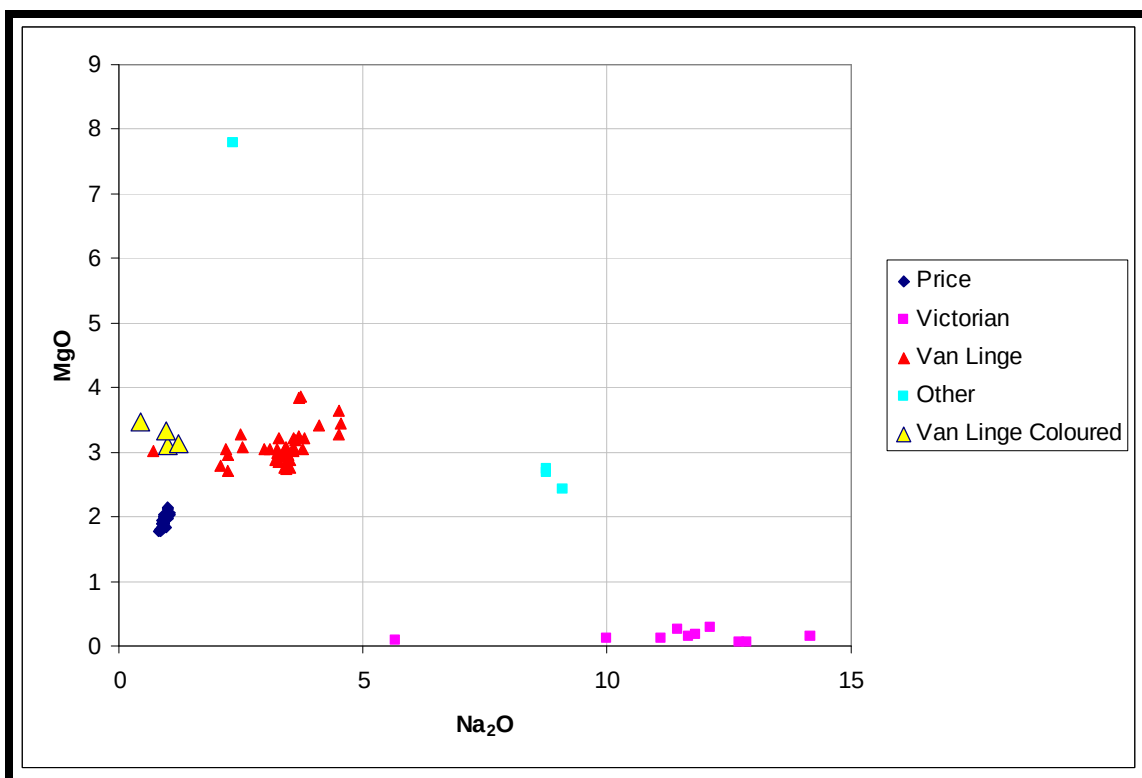


Figure 3-56 SEM-WDS plot of MgO against Na₂O (wt%)

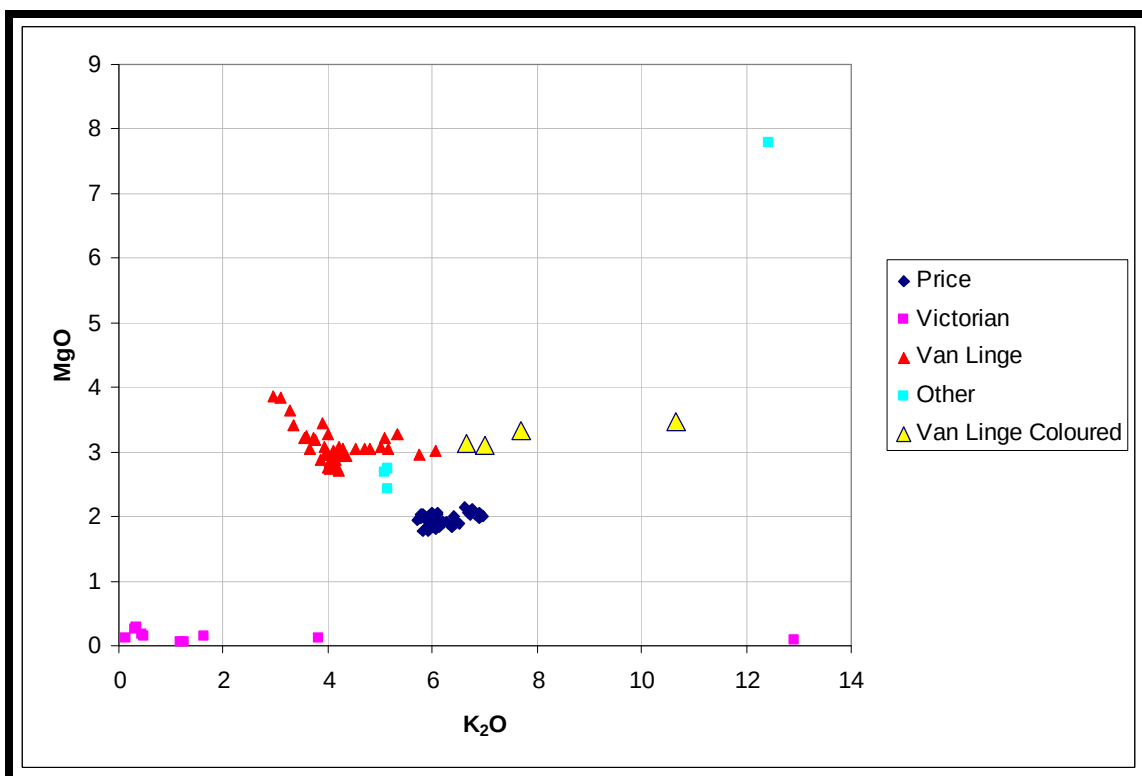


Figure 3-57 SEM-WDS plot of MgO against K₂O (wt%)

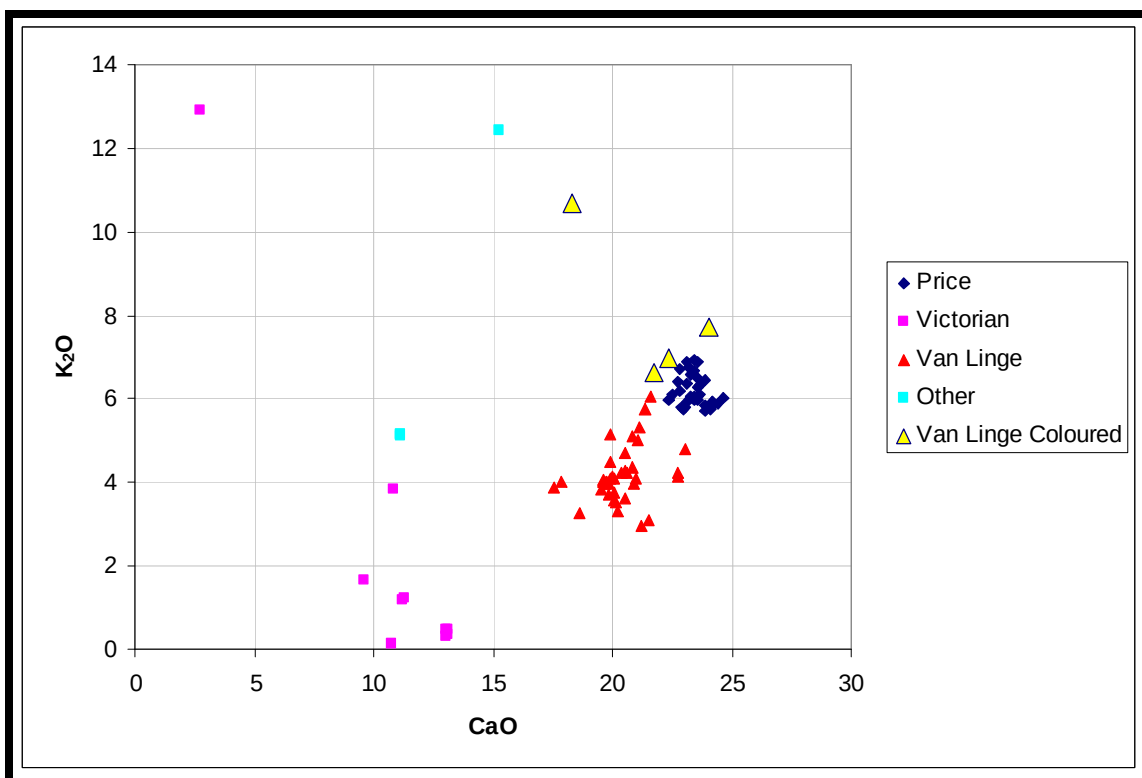


Figure 3-58 SEM-WDS plot of K₂O against CaO (wt%)

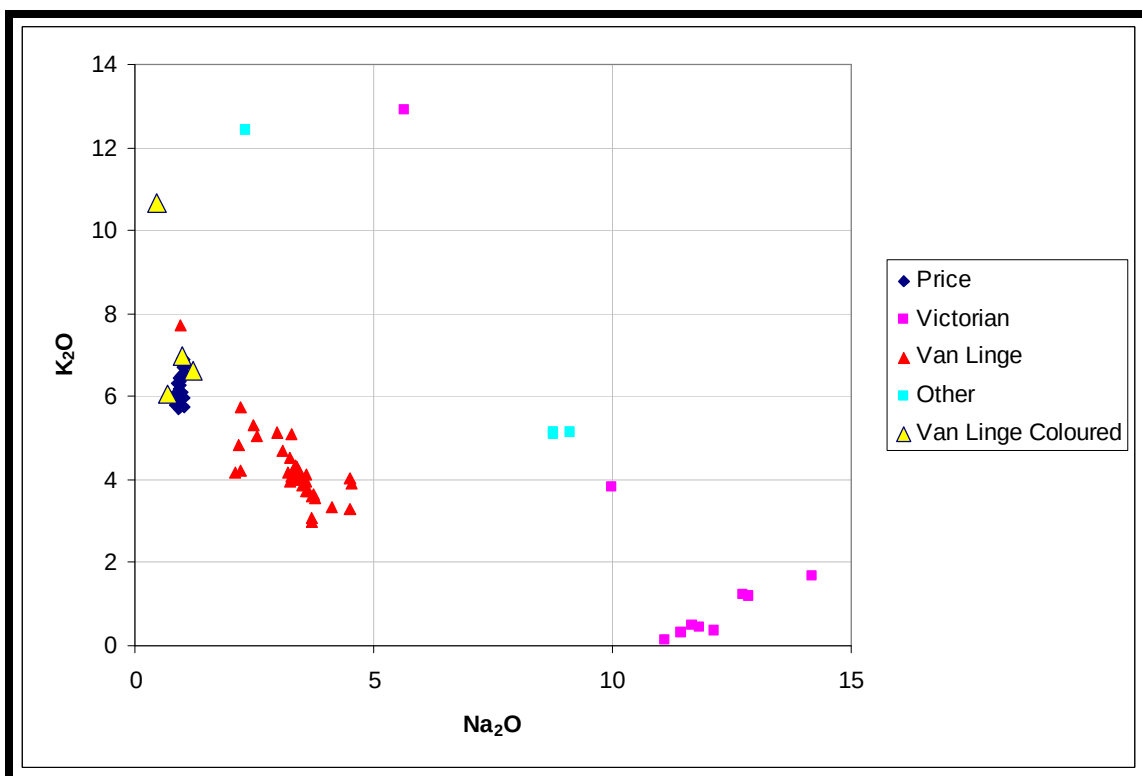


Figure 3-59 SEM-WDS plot of K₂O against Na₂O (wt%)

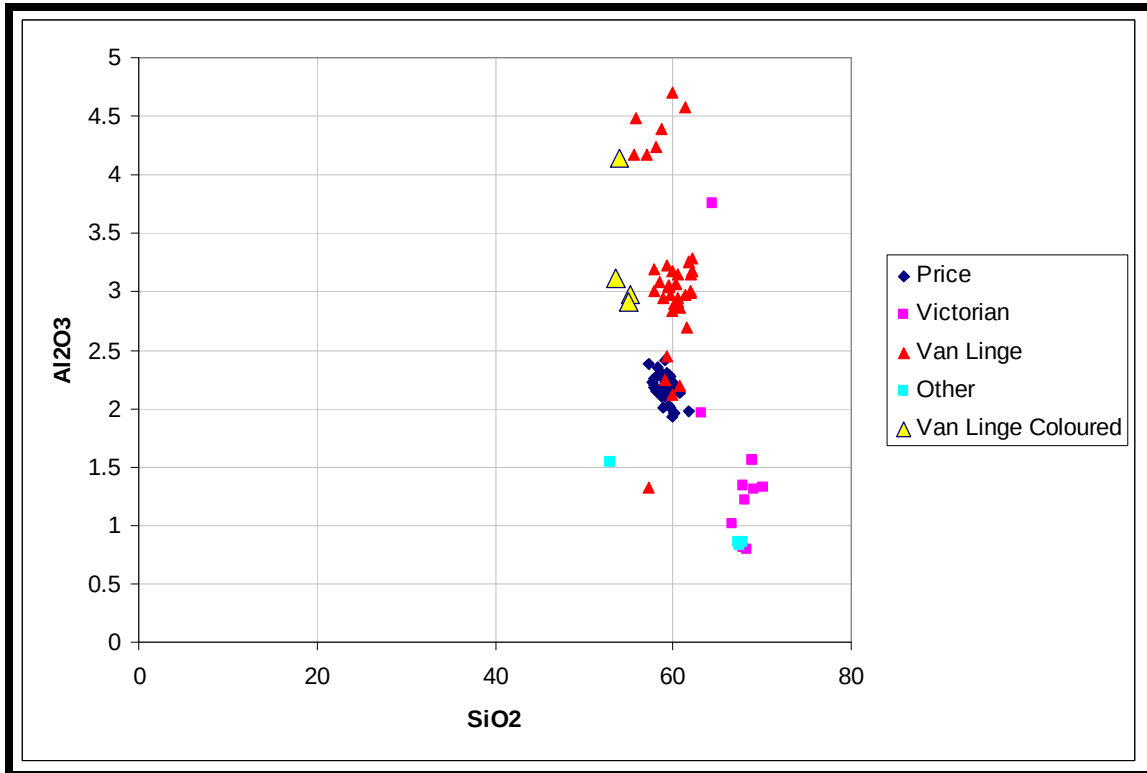


Figure 3-60 SEM-WDS plot of Al_2O_3 against SiO_2 (wt%)

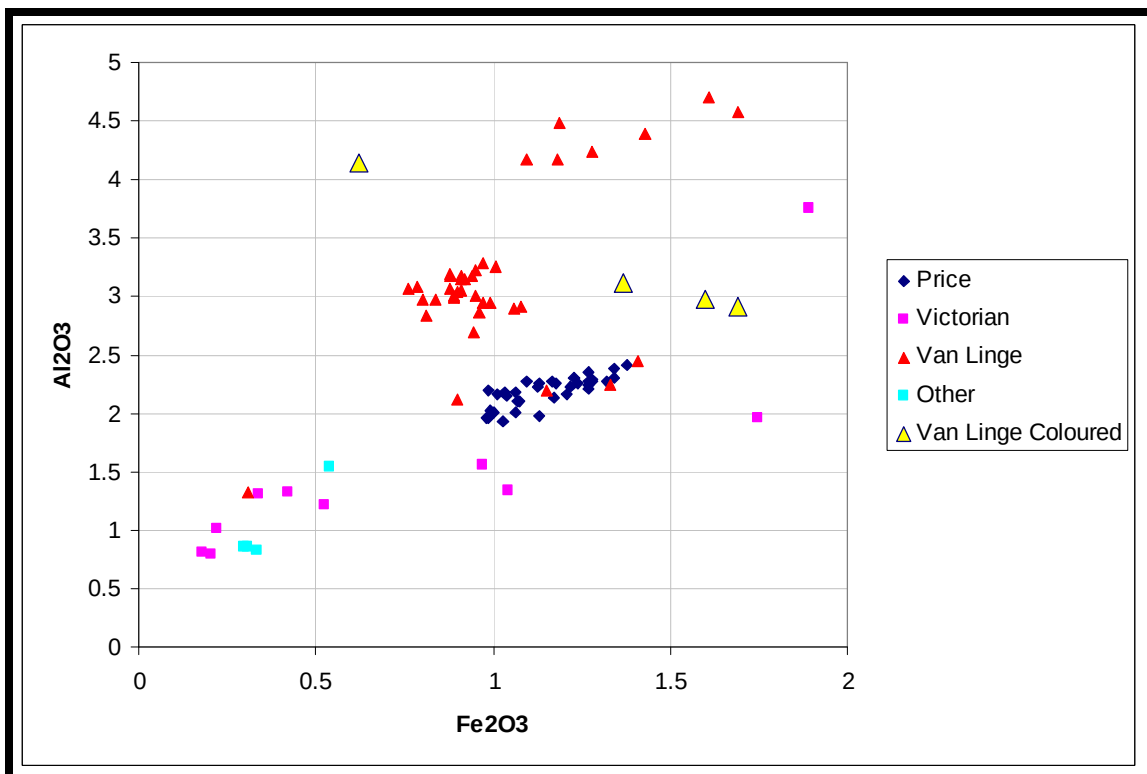


Figure 3-61 SEM-WDS plot of Al_2O_3 against Fe_2O_3 (wt%)

3.12.1.1 Principal Component Analysis

Principal Component Analysis (PCA) was carried out on the SEM-WDS results for the samples (Figure 3-62). This statistical analysis is used to interpret multi-dimensional data, it is especially useful when it can be difficult to visualise and subsequently interpret true patterns within large data sets. Although in the case of the Christ Church samples, the groups seem visually fairly obvious, this analysis was undertaken to determine what the most influential variables in the data were, and to then use this information to determine which variables should be used to group the data in the cluster analyses. PCA determines the covariance matrix of the data and from there the eigenvectors and eigenvalues that may be present. The eigenvector with the highest eigenvalue is the first Principal Component (PC1). This analysis, therefore, reduces the number of dimensions in the data. The PCA of the data indicated that the first two components accounted for 88.7% of the data. Although a greater proportion of the data could be accounted for by considering the first 3 components, PC3 only accounted for an extra 5.9% of the data, and the information lost by ignoring this and subsequent components is very small.

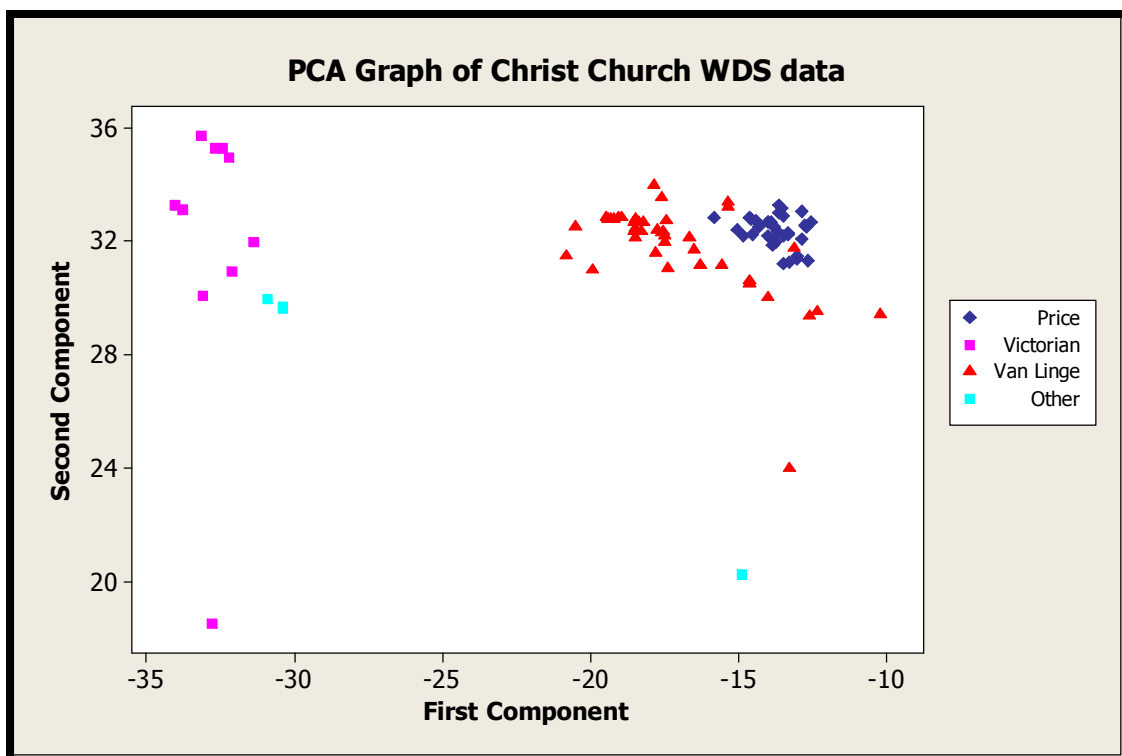


Figure 3-62 Principal Component Analysis of Christ Church SEM-WDS data

Based on the PCA, four variables were deemed the most influential in terms of the two Principal Components; Na_2O , SiO_2 , K_2O , and CaO . These four variables were then used as the basis for the cluster analyses of the data. It was decided to cap the groups at a similarity level of 80%. Two methods of analysis were chosen, the Single Linkage method, which links the clusters based on the shortest distance between the samples (also known as the ‘nearest neighbour’ method) (Figure 3-63), and the Ward Linkage method which determines the clusters based on the sum of the squared deviations between the points and the centroid (Figure 3-64). The Ward method tends to group similar numbers of samples into each group but the groups are more circular in shape. It was decided to use these two methods and then to evaluate the results and any samples that were put into the same groups with each method would be deemed as a true group.

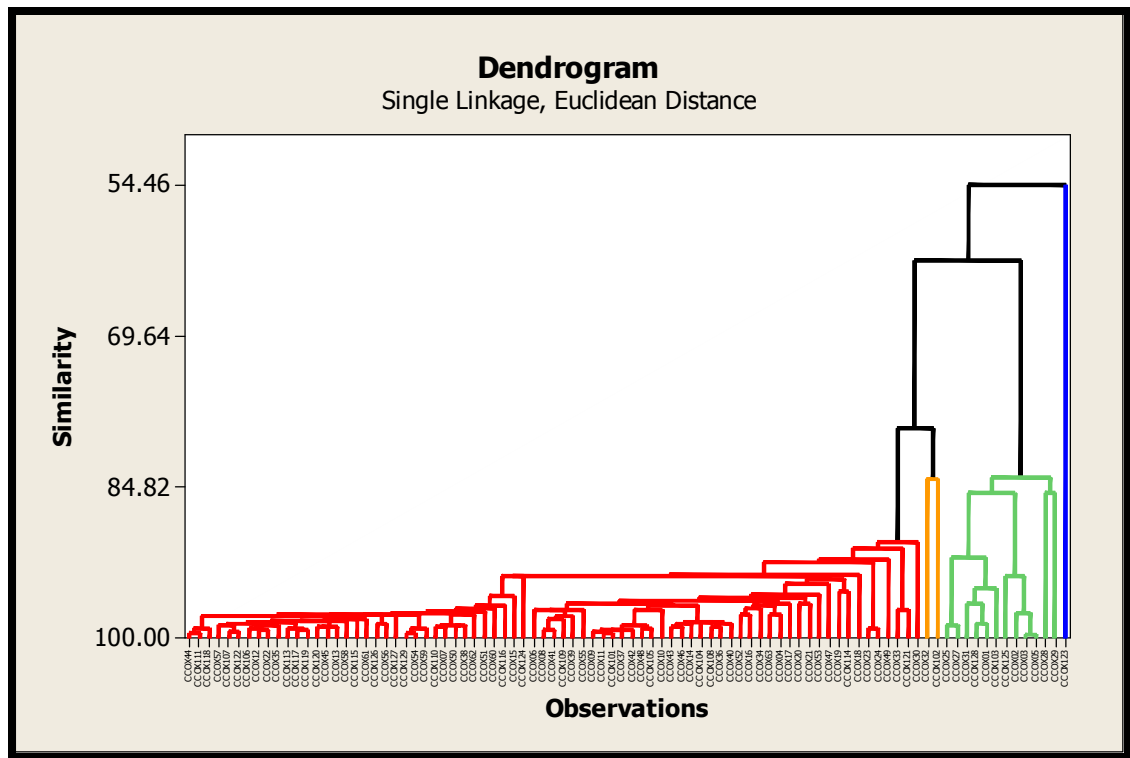


Figure 3-63 Dendrogram of Single Linkage, Euclidean Distance, highlighting four main groups

Due to the large number of samples, this graph makes it difficult to see which are in each group and so Table 3-13 below indicates the groups which this method of cluster analysis has placed the samples into.

Group 1	Group 1 (cont)	Group 2	Group 3	Group 4
CCOX44	CCOX109	CCOX32	CCOX25	CCOX123
CCOX111	CCOX39	CCOX102	CCOX27	
CCOX118	CCOX55		CCOX31	
CCOX57	CCOX09		CCOX128	
CCOX107	CCOX11		CCOX01	
CCOX122	CCOX101		CCOX103	
CCOX106	CCOX37		CCOX125	
CCOX12	CCOX42		CCOX02	
CCOX22	CCOX48		CCOX03	
CCOX35	CCOX105		CCOX05	
CCOX113	CCOX10		CCOX28	
CCOX117	CCOX43		CCOX29	
CCOX119	CCOX46			
CCOX120	CCOX14			
CCOX45	CCOX104			
CCOX13	CCOX108			
CCOX58	CCOX36			
CCOX115	CCOX40			
CCOX61	CCOX52			
CCOX126	CCOX16			
CCOX56	CCOX34			
CCOX127	CCOX63			
CCOX129	CCOX04			
CCOX54	CCOX17			
CCOX59	CCOX20			
CCOX110	CCOX21			
CCOX07	CCOX53			
CCOX50	CCOX47			
CCOX38	CCOX19			
CCOX62	CCOX114			
CCOX51	CCOX18			
CCOX60	CCOX23			
CCOX116	CCOX24			
CCOX15	CCOX49			
CCOX124	CCOX33			
CCOX06	CCOX121			
CCOX08	CCOX30			
CCOX41				

Table 3-13 Groups based on the Single Linkage, Euclidean Distance cluster analysis

By comparing these groups with the original SEM-WDS data (see Appendix B), it can be seen that all the samples in Group 1 are from the 17th century. Although visually the samples can clearly be separated into Van Linge and Price with this statistical method they are all deemed to form one group. Group 2 is a coloured Van Linge sample and the Medieval sample. Group 3 is Victorian and the three unknown samples, while Group 4 is an outlier. It is interesting to note that CCOX123, the blue sample, which had similarities with both the Victorian samples and the Medieval

sample has been classed as an outlier, yet the Medieval sample (CCOX102) has been placed in Group 2.

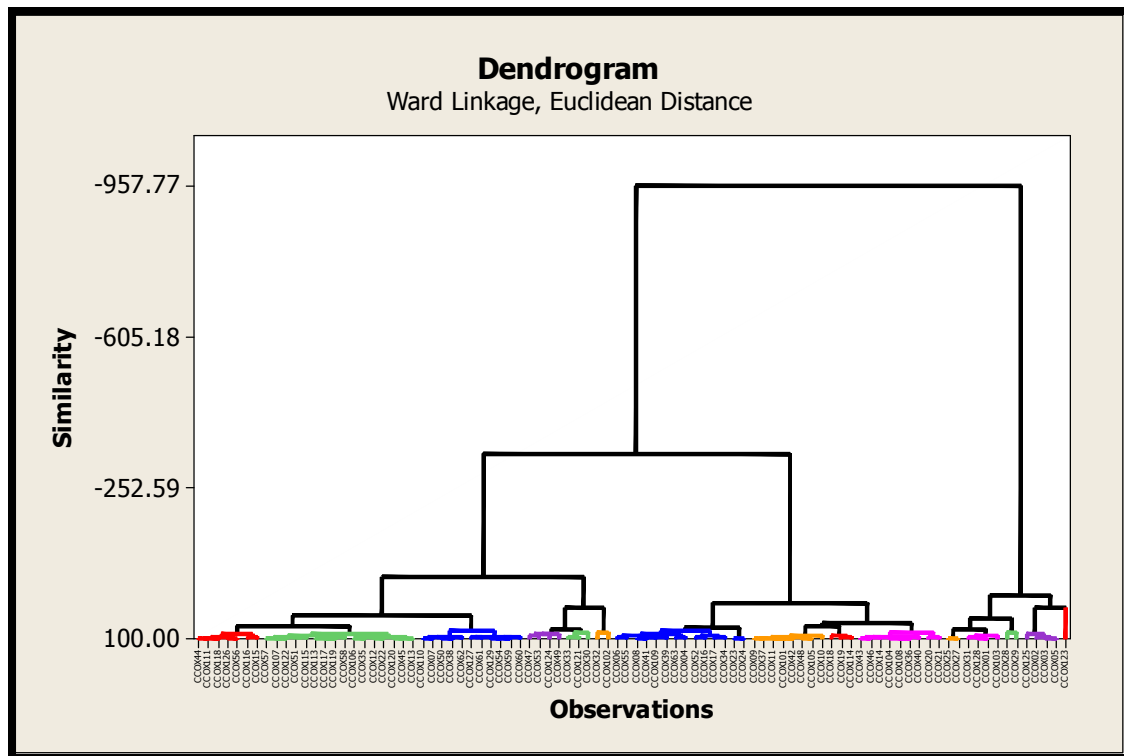


Figure 3-64 Dendrogram of Ward Linkage, Euclidean Distance showing 16 groups

The Ward Linkage, Euclidean Distance determination of groups defined 16 smaller groups in the data (but this method does tend to make groups of similar sizes). The groups are outlined in Table 3-14 below.

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Price	Price	Price	VL	VL	VL/Med	VL	VL
CCOX44	CCOX57	CCOX110	CCOX47	CCOX33	CCOX32	CCOX06	CCOX23
CCOX111	CCOX107	CCOX07	CCOX53	CCOX121	CCOX102	CCOX55	CCOX24
CCOX118	CCOX122	CCOX50	CCOX124	CCOX30		CCOX08	
CCOX126	CCOX51	CCOX38	CCOX49			CCOX41	
CCOX56	CCOX115	CCOX62				CCOX109	
CCOX116	CCOX113	CCOX127				CCOX39	
CCOX15	CCOX117	CCOX61				CCOX63	
	CCOX119	CCOX129				CCOX04	
	CCOX58	CCOX54				CCOX52	
	CCOX106	CCOX59				CCOX16	
	CCOX35	CCOX60				CCOX17	
	CCOX12					CCOX34	
	CCOX22						
	CCOX120						
	CCOX45						
	CCOX13						

Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16
VL	VL	VL	Victorian	Victorian	Victorian	Vic/Other	Victorian
CCOX09	CCOX18	CCOX43	CCOX25	CCOX31	CCOX28	CCOX125	CCOX123
CCOX37	CCOX19	CCOX46	CCOX27	CCOX128	CCOX29	CCOX02	
CCOX11	CCOX114	CCOX14		CCOX01		CCOX03	
CCOX101		CCOX104		CCOX103		CCOX05	
CCOX42		CCOX108					
CCOX48		CCOX36					
CCOX105		CCOX40					
CCOX10		CCOX20					
		CCOX21					

Table 3-14 Table of groups as defined by Ward Linkage, Euclidean Distance Cluster Analysis

Table 3-14 shows that all of the samples with the exception of two are placed in the groups which were visually identified based on composition i.e. Price, Van Linge, Victorian. The two exceptions are CCOX102 (the Medieval sample), and CCOX125 (Victorian). Again it will be noted that CCOX123 which has both Medieval and Victorian qualities has been identified statistically as being an outlier. In both types of cluster analysis CCOX32 and CCOX102 have been grouped together, according to the original data (Appendix B), these samples have similar potassium and calcium levels (10-13 wt% K₂O and 15-18 wt% CaO). One of the major differences between these two samples and CCOX123 is the CaO level, which in the latter sample is very low at 2.78 wt% compared to all the other samples.

3.12.1.2 Discriminant Analysis

Because the samples could be assigned to groups visually it was possible to perform Discriminant Analysis on the data. This requires that the data be assigned to groups and then based on a set of predictors, the analysis will determine whether the groups are true groups or not. The Discriminant Analysis requires that all the samples be assigned to groups beforehand and that each group contains at least two samples. The predictors must be variables that are not correlated with each other, and so in this case the following oxides were used: Na₂O, SiO₂, MgO, Al₂O₃, TiO₂, P₂O₅, K₂O, CaO, SO₃, Cl, Cr₂O₃, Fe₂O₃, MnO, CoO, NiO, CuO, ZnO, SnO, Sb₂O₅, BaO, PbO.

Group	1	2	3	4
No. Samples	34	10	42	4

Table 3-15 The number of samples in each visually identified group

	True Groups			
Group	1	2	3	4
1	34	0	0	0
2	0	10	0	0
3	0	0	42	0
4	0	0	0	4
Total No.	34	10	42	4
No. Correct	34	10	42	4

Table 3-16 Defined Groups vs. True Groups

The results of the Discriminant Analysis (Table 3-15 and Table 3-16) show that of the 90 samples analysed all of them were visually assigned to the correct statistical group based on the major and minor elemental compositions.

The results of the SEM-WDS analyses has shown that the samples of Christ Church glass can be attributed to four main groups, these comprise two distinct groups of 17th century HLLA glass attributed to Price and Van Linge, a more dispersed groups of Victorian samples, and a group labelled as other which contains one Medieval sample and three samples as yet unascribed to a specific artist or period. The Van Linge group contains four coloured samples which are in some cases more dispersed from the rest of the Van Linge group.

3.12.2 LA-ICP-MS

After analysis of the major and minor elements in the glass, analyses of the trace elements were undertaken using Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS). Because the SEM-WDS analyses had highlighted two distinct groups among the 17th century glass, it was decided that the Price and Van Linge samples would be the focus of these analyses. 24 samples were analysed using LA-ICP-MS; the samples chosen were all known Price or Van Linge samples, for example, four of the Van Linge samples came from identifiable parts of the windows such as the arms of the King family, or from ‘Christ Disputing with the Doctors’. As with the analyses of the major and minor elements, the analyses of the trace elements shows that in most cases the Price and the Van Linge samples fall into distinct groups.

The Price and Van Linge samples are characterised in the Table 3-17 below. Sample CCOX15, which is part of the Price group, in almost all cases forms the lowest end of the characterisation bracket. The Van Linge samples group together in most cases, although there are two outliers to this group samples CCOX19 and CCOX121. CCOX121 is the dark blue sample flashed with white (colourless) glass; in this case it was the bulk of the blue glass that was analysed.

Element	Price (ppm)	Van Linge (ppm)
Al	9364-11022	13386.04-20729.17
Ti	715-883	1016.79-1499.16
V	19.54-23.97	12-14
Cr	14.45-17.91	12.1-14.26
Mn	847.83-1310.68	4478.9-6366.01
Co	3.93-4.89	6.93-24.58
Ni	14.83-17.76	21.69-27.55
Cu	91.73-100.29	48.1-59.24
Zn	214.47-284.08	110.29-168.58
Ga	5.6-7.02	17.15-20.89
Ge	1.43-2.02	0.676-0.914
As	6.13-7.58	9.99-97.14
Cs	0.99-1.28	0.453-0.7
Ba	428.97-563.74	1296.16-2898.32
Bi	0.163-0.3	0.109-18.24
Pb	114.42-372.89	81.21-679.67

Table 3-17 Characterisation of Price and Van Linge based on trace elements

In terms of the Van Linge samples, CCOX19 (colourless/grey) and CCOX121 (dark blue) both have higher V, Cr, Zn, and Ge contents, and lower Ga contents. While the colourless CCOX19 also has lower Mn, Cu, and Ba; the dark blue CCOX121 has higher Co, Ni, Cu, As, Cs and Bi. The latter can mostly be explained by the blue colour of the sample, for example, Co, Ni, and Cu are likely to all indicate the same ore source for the colourant used, in this case cobalt.

The Sr and Ca are often linked as they usually come from the same source (Figure 3-65), the relationship between the Sr and Ca can often be used to determine the different lime sources. Figure 3-65 indicates that CCOX19 has a different lime source to the rest of the 17th century samples. Figure 3-66 indicates that the Price samples and the Van Linge samples have similar Y levels but very different Mn levels. The exception to this being CCOX19 and CCOX121.

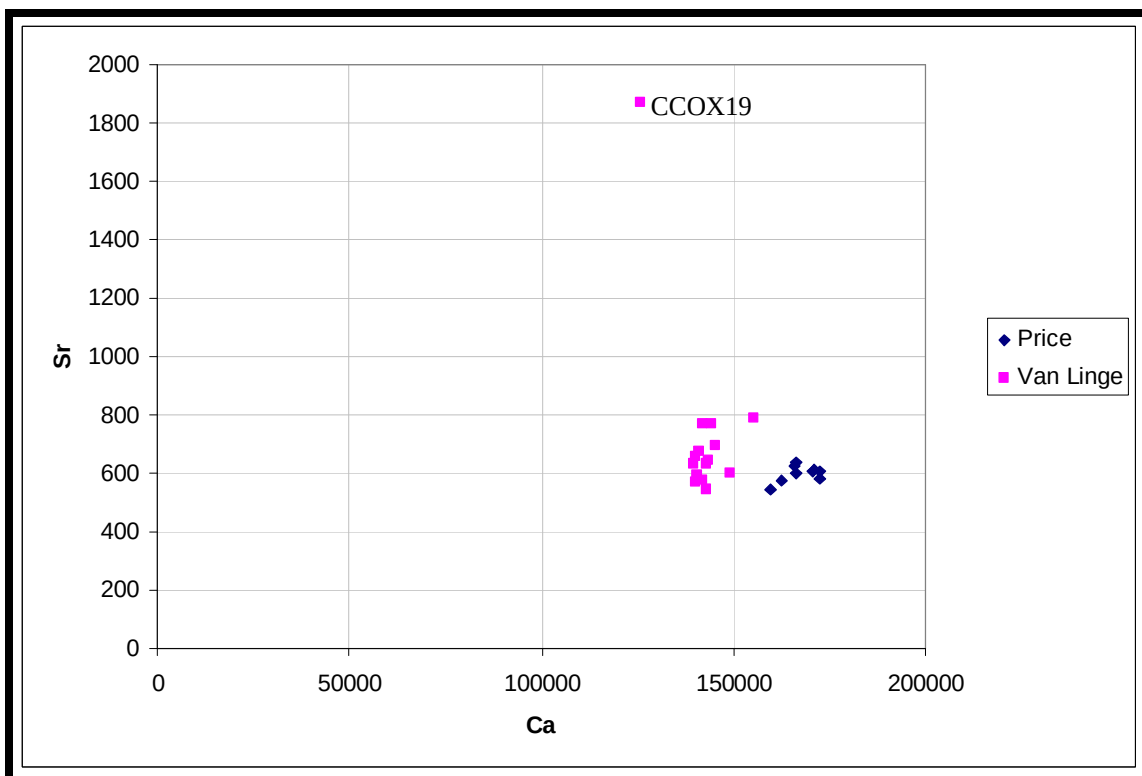


Figure 3-65 LA-ICP-MS plot of Sr against Ca (ppm)

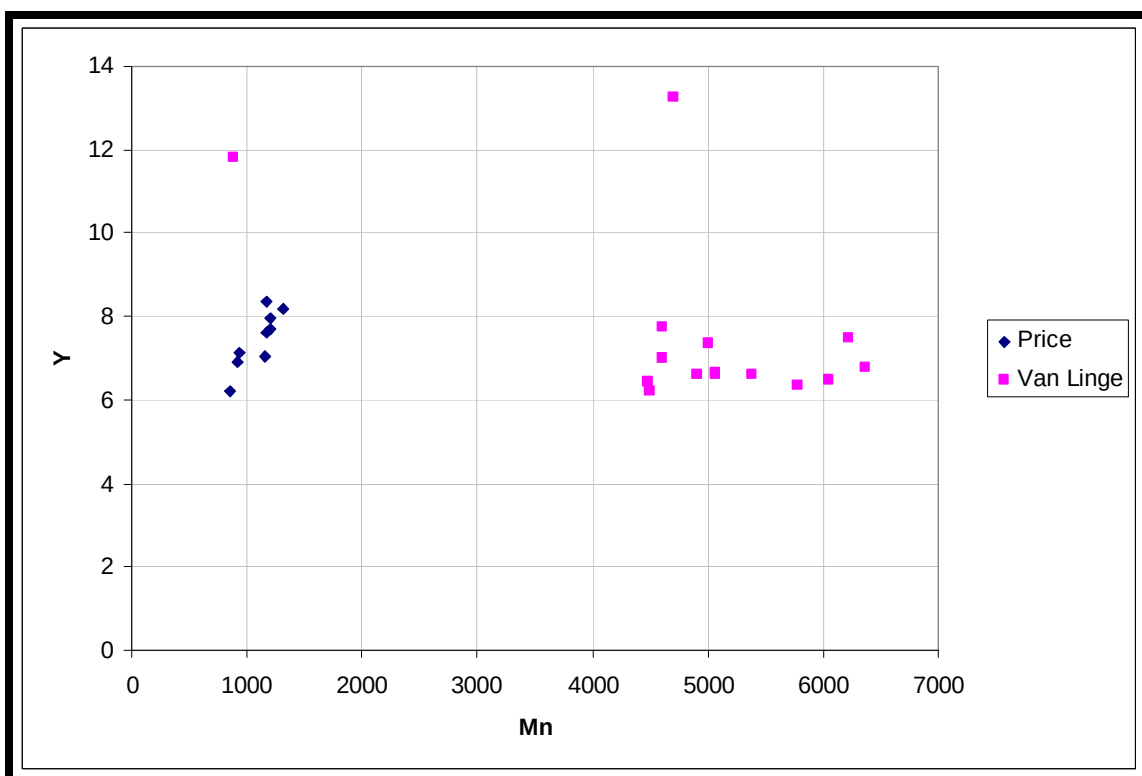


Figure 3-66 LA-ICP-MS plot of Y against Mn (ppm)

Some positive correlations can be seen amongst the Price samples most notably in the rare earth elements (REEs), Fe and Zr. The elements which show the most

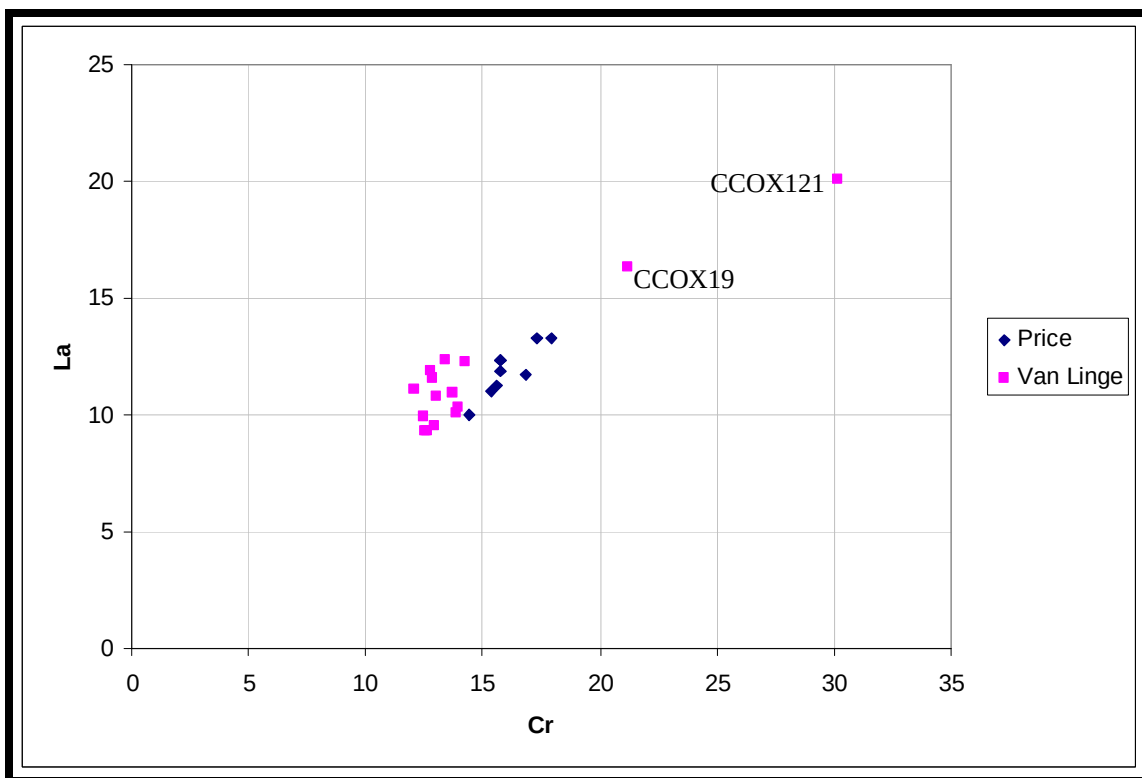


Figure 3-68 LA-ICP-MS plot of La against Cr (ppm)

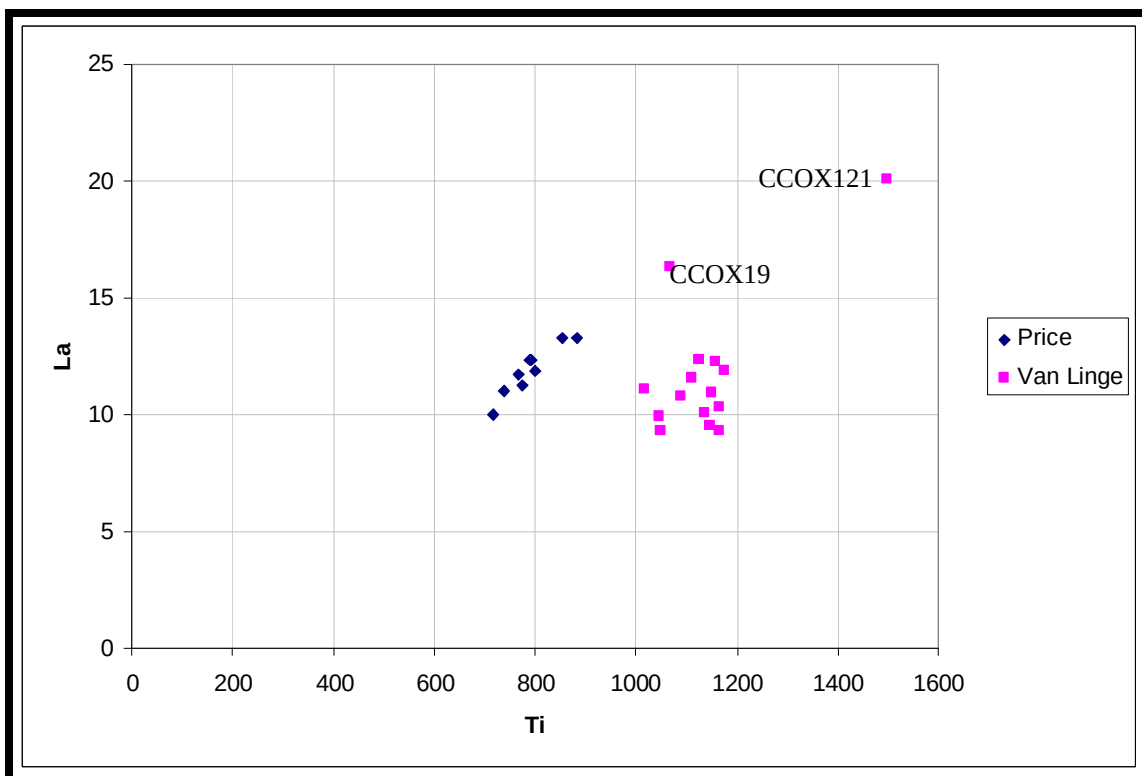


Figure 3-69 LA-ICP-MS plot of La against Ti (ppm)

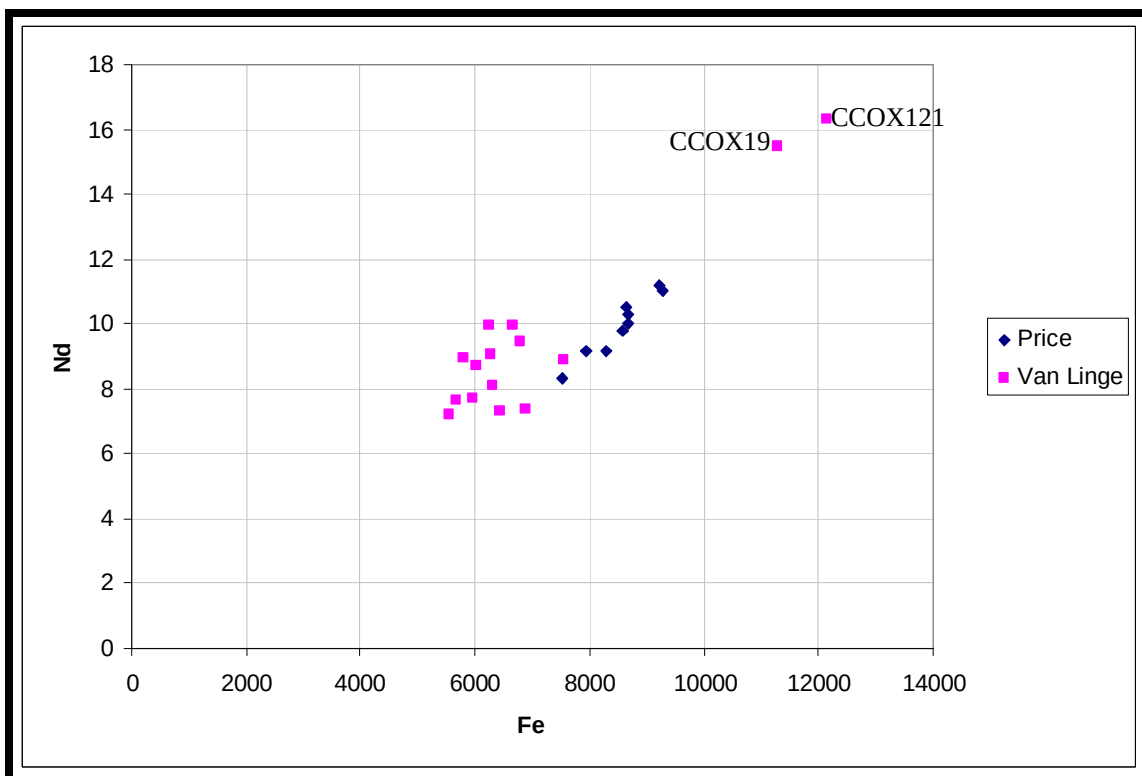


Figure 3-70 LA-ICP-MS plot of Nd against Fe (ppm)

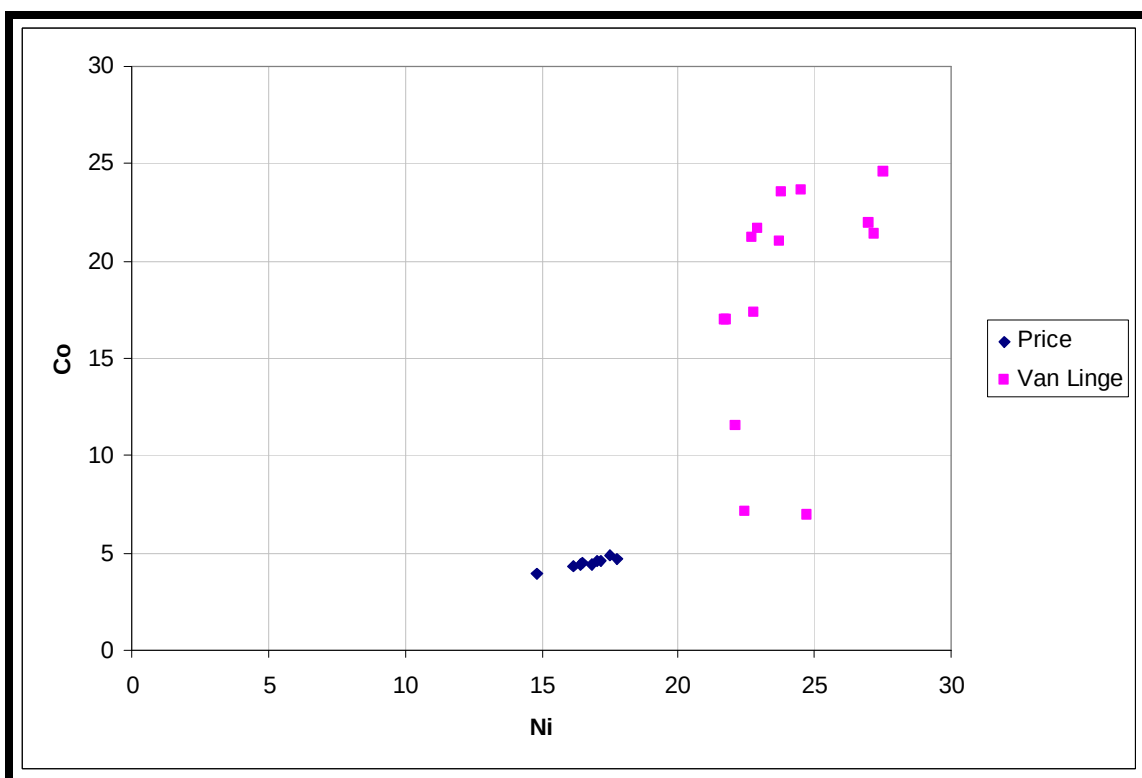


Figure 3-71 LA-ICP-MS plot of Co against Ni (ppm), CCOX121 has been left off this plot as the high levels of both Co and Ni skewed the data

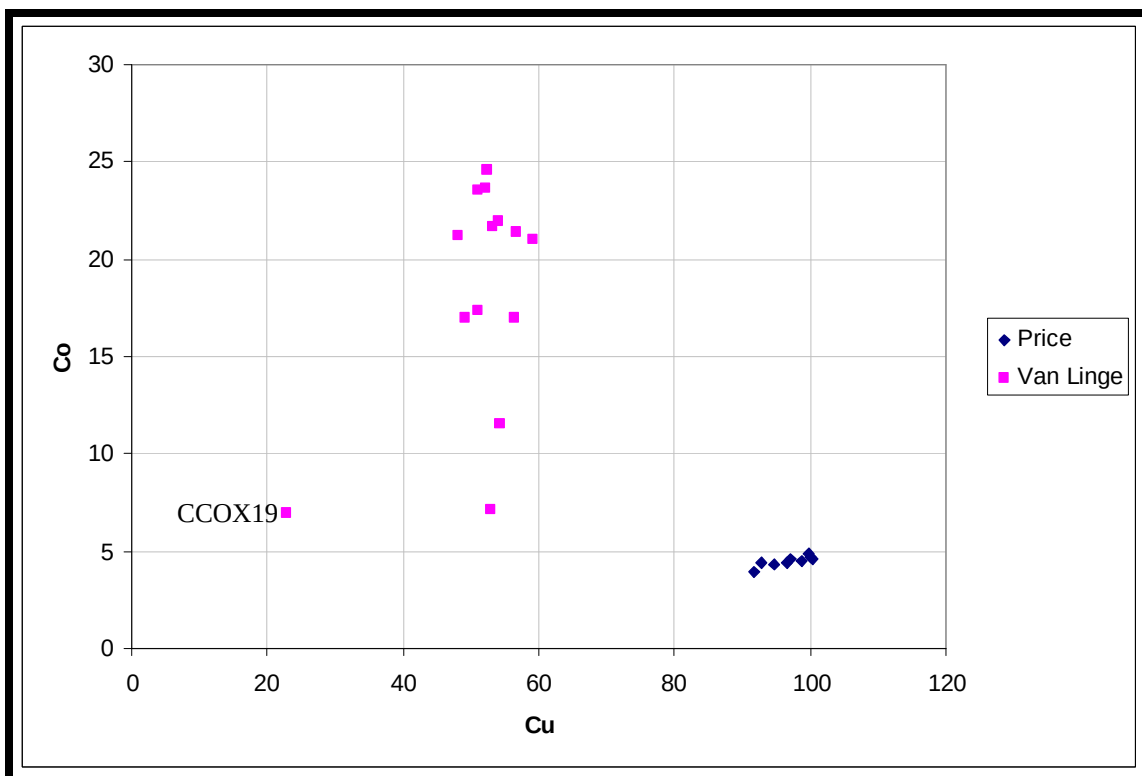


Figure 3-72 LA-ICP-MS plot of Co against Cu (ppm), CCOX121 has been left off this plot as the high levels of both Co and Cu skewed the data

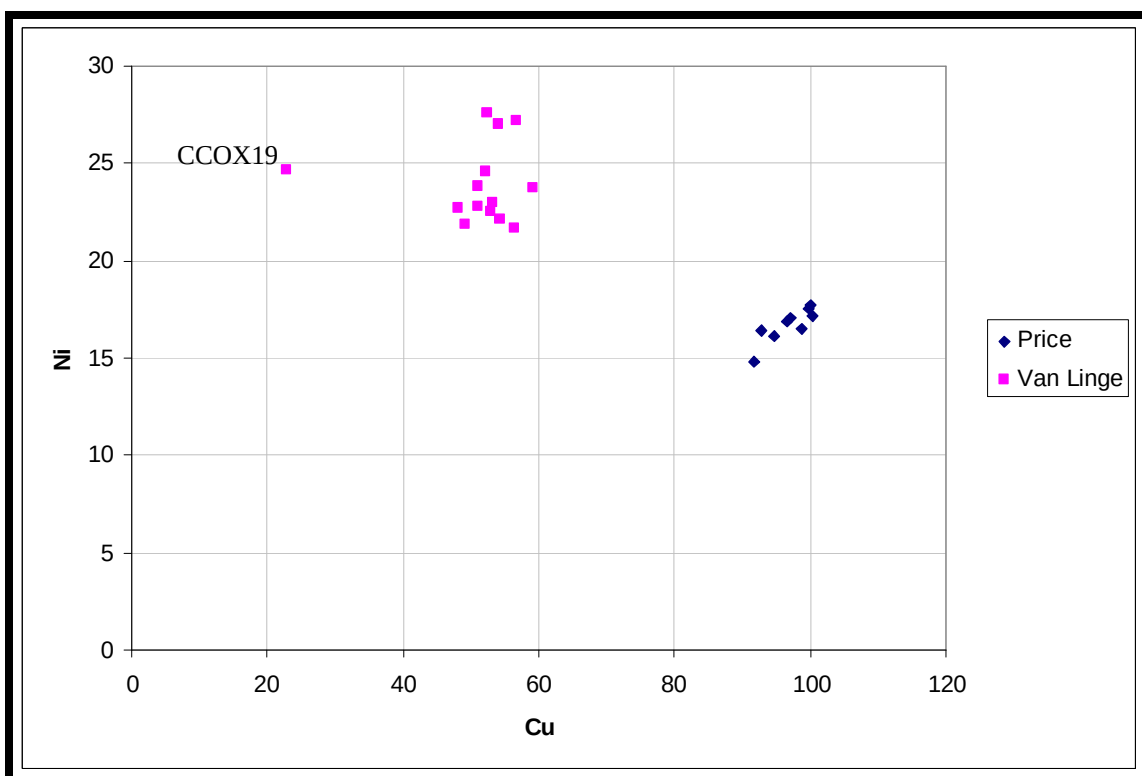


Figure 3-73 LA-ICP-MS plot of Ni against Cu (ppm), CCOX121 has been left off this plot as the high levels of both Ni and Cu skewed the data

3.12.2.1 Principal Component Analysis

Principal Component Analysis was used on the trace elemental data (Figure 3-74), it was decided to remove the variables that would skew the data due to the quantity of the element present, such as Ca, Al, Mn and Fe. The results indicated that the first two Principal Components accounted for 96.5% of the data.

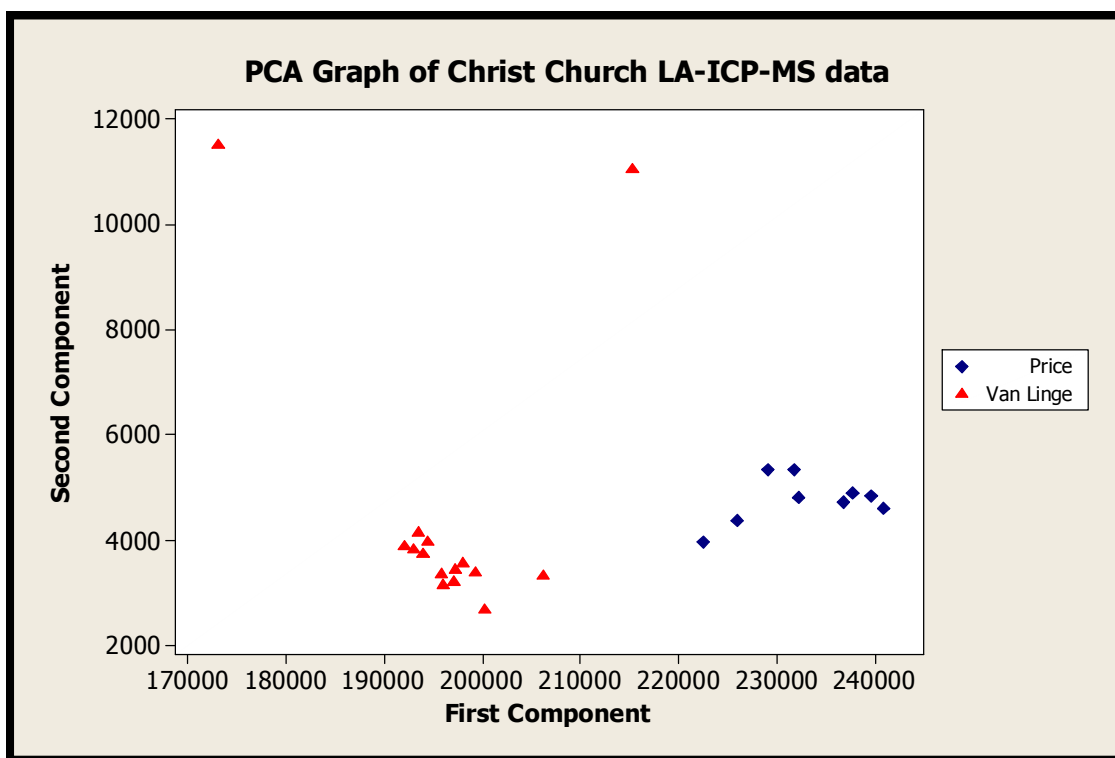


Figure 3-74 Principal Component Analysis plot of the Christ Church LA-ICP-MS data

The most influential variables in terms of these two components are Co, As and Ba. Ni, Bi, Ti and Pb also have an influence, although it is not to the same extent as the former elements. These seven elements were used as the main variables in the subsequent cluster analysis. The cluster observations were capped at an 80% similarity level, again, in order to determine the groups present.

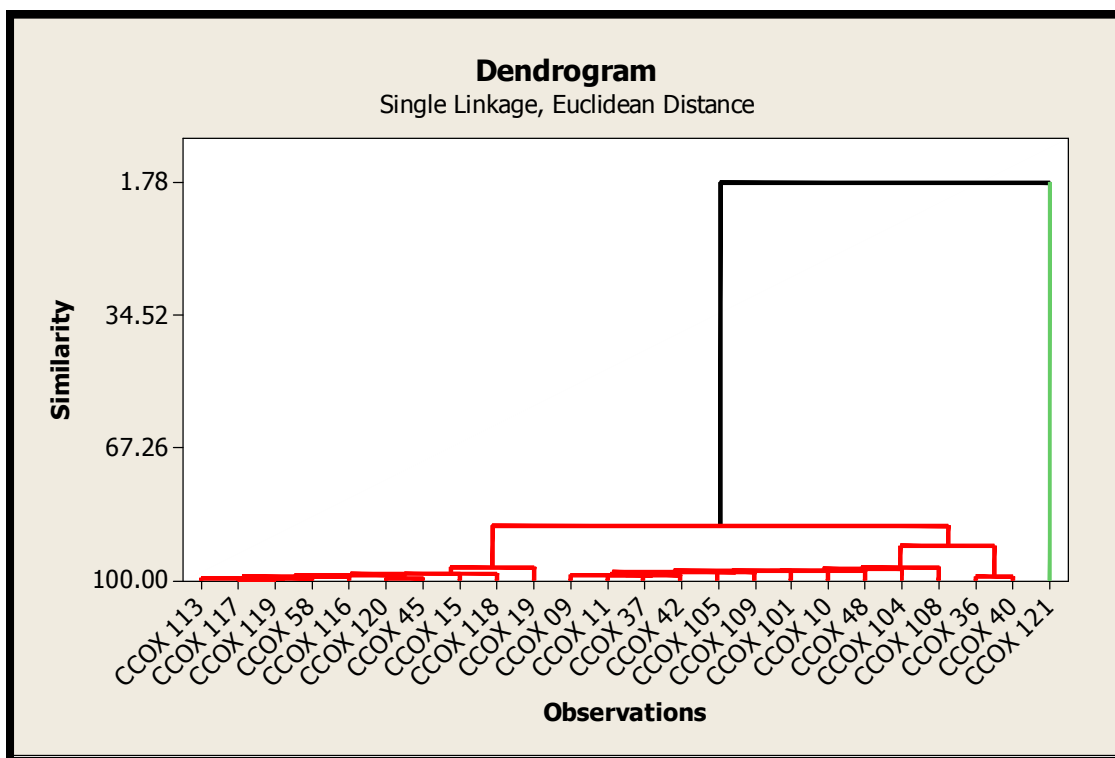


Figure 3-75 Dendrogram of Single Linkage, Euclidean Distance cluster analysis of trace elements

The Single Linkage, Euclidean Distance analysis defined two groups, or more precisely one group and one outlier (Figure 3-75). The outlier in this case was sample CCOX121, which is dark blue (all the other samples which were analysed using LA-ICP-MS were colourless). The cluster analysis will therefore have defined this sample as a noticeable outlier because the analysis was based on variables which included colourants and CCOX121 is coloured and therefore has high levels of these elements present. The single linkage method of cluster analysis does not differentiate between the 17th century samples using the trace elements.

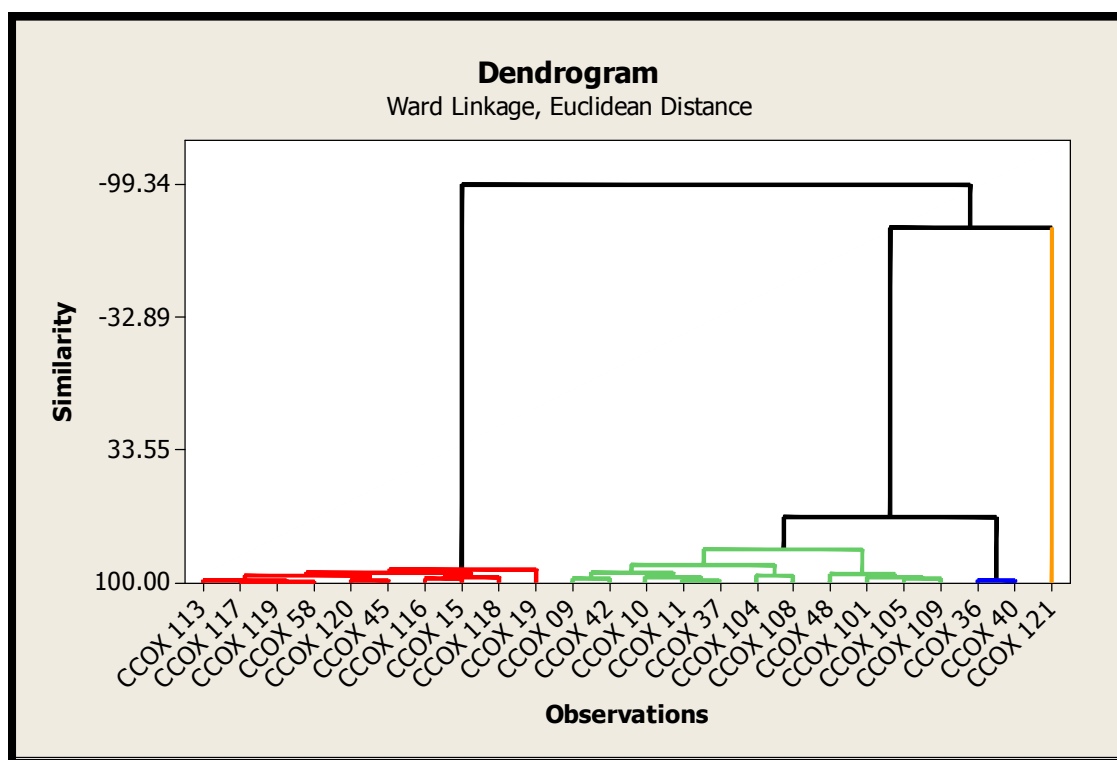


Figure 3-76 Dendrogram of Ward Linkage, Euclidean Distance cluster analysis of trace elements

The Ward Linkage, Euclidean Distance analysis (Figure 3-76) defined four groups (Table 3-18) within the data at an 80% similarity level.

Group 1	Group 2	Group 3	Group 4
Price	Van Linge		
CCOX113	CCOX09	CCOX36	CCOX121
CCOX117	CCOX42	CCOX40	
CCOX119	CCOX10		
CCOX58	CCOX11		
CCOX120	CCOX37		
CCOX45	CCOX104		
CCOX116	CCOX108		
CCOX15	CCOX48		
CCOX118	CCOX101		
	CCOX105		
CCOX19	CCOX109		

Table 3-18 Groups defined by Ward Linkage, Euclidean Distance cluster analysis of trace elements

All of the samples in Group 1 with the exception of CCOX19 were assigned on art historical grounds to Price, whereas CCOX19 was assigned to Van Linge. The analysis of the major and minor elements confirmed sample CCOX19 as being Van Linge. But, as was mentioned earlier, CCOX19 is an unusual sample and does appear on some plots as an outlier to the Van Linge group. It is perhaps more surprising that the

statistical analysis has assigned this sample to the Price group. The variables deemed the most influential over the data and therefore used in the cluster analysis included Mn; the Mn level in CCOX19 is more similar to those of the Price samples than the Van Linge samples, although overall, the sample is compositionally a Van Linge. In terms of the different statistical grouping methods, the Single Linkage cluster analysis could not separate the 17th century samples into different groups whereas this has been achieved with the Ward Linkage analysis.

Discriminant Analysis was also performed on the data to determine if the (pre)defined groups of Price and Van Linge samples were true groups or not. Group 1 (Price) contained 9 samples and Group 2 (Van Linge) contained 15 samples. According to the Discriminant Analysis all 24 samples had been assigned to the correct groups, using Li, B, Ti, Co, Cu, Rb, Sr, Y, Ag, Sn, and Sb as the predictors.

3.12.3 RI

An attempt was made to determine the RI of samples of the Price and Van Linge glass. This proved problematic as the RI of these glasses proved to be outside the range of the standard Locke oils calibrated for use with the GRIM 3. In order to obtain a 'ball park' figure for the RI, an Elipsometer was used. The elipsometer uses polarized light to characterise the optical properties of samples. Samples of both Price and Van Linge were found to be in the 1.55 region, but, the Elipsometer could not provide the precision of the GRIM 3. A further attempt was made to determine the RI of the samples by using a high RI liquid, up to 1.555. Attempts to use this oil also proved fruitless, therefore, the RI of the 17th century samples must be higher than 1.555. In order to assess whether RI could be used on archaeological glass, samples from a range of archaeological periods were analysed on the GRIM 3 using the standard silicon oils (A-C). Table 3-19 shows the RIs of the archaeological glasses sampled.

Sample	Date	RI	Range	SD
COP9	Egyptian	1.52163	1.52111-1.52187	0.0002568
UPP3	Egyptian	1.53137	1.53126-1.53146	0.0000624
PD26	Roman	1.51270	1.51263-1.51276	0.0000362
PD29	Roman	1.51775	1.51755-1.51792	0.0001154
CCOX102	Medieval	1.55049	1.55041-1.55060	0.0000509
CCOX123	Med/Vic	1.51905	1.51882-1.51925	0.0001587

CCOX01	Victorian	1.52944	1.52932-1.52948	0.0000411
CCOX103	Victorian	1.53101	1.53057-1.53146	0.0002335

Table 3-19 RIs of archaeological glasses

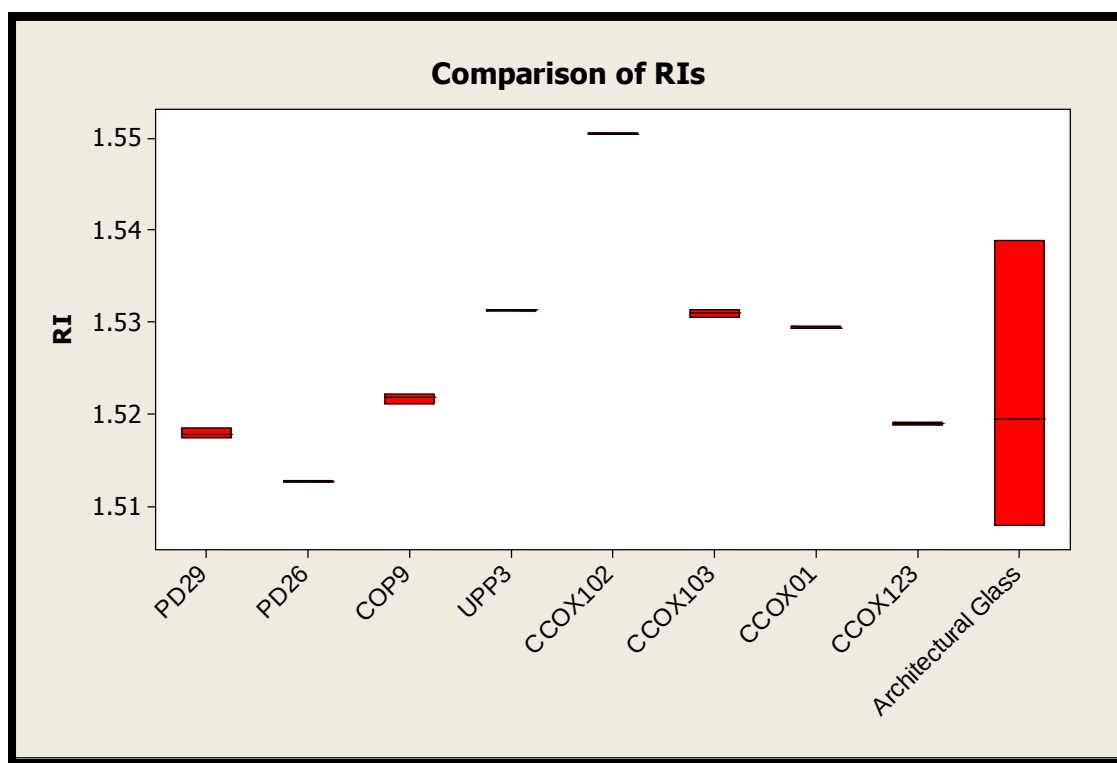


Figure 3-77 Plot of RIs of samples compared to the Architectural Glass classification category

Figure 3-77 shows a comparison of the archaeological glass RIs with the range of RIs that are covered by the forensic architectural glass category. This plot (Figure 3-77) and Table 3-19 shows that the RI analysis of the samples can differentiate between all but two of the samples, those being UPP3 and CCOX103, which have overlapping RI distributions. All of the samples with the exception of the Medieval sample (CCOX102) fall within the RI ‘forensic’ category of ‘Architectural Glass’ (see section 4.4.1). The RI analysis also shows that the samples from the same archaeological period have very different RIs. For example, the two Roman samples have mean RIs of 1.51775 (PD29) and 1.51270 (PD26). RI reflects the major element composition of the sample (Huang et al. 1978), and in this case has indicated the similarity between samples of different periods i.e. UPP3 and CCOX103 (Egyptian and Victorian), and the differences between samples from the same period i.e. PD26 and PD29 (both Roman). Unfortunately, due to the high RI of the samples, a comparison of the 17th century glass was not possible with the available facilities. The highest RI of the samples analysed (excluding the 17th century samples) was the Medieval sample

(CCOX102). This RI was noticeably higher than the other samples, this sample is characteristically different in the major element composition by having very high potassium (12.44 wt%) and lime (15.24 wt%) levels. What this sample has in common with the 17th century samples is the high amount of lime in the composition, although the CCOX102 has less than the 17th century glass. This suggests that the CaO contents of the samples are one of the determining factors of the RI, and the high levels in the HLLA glass is the cause of the difficulty in determining the RI for these samples.

3.13 Discussion

The main characteristic features of High Lime, Low Alkali (HLLA) glass are the low alkali levels ($\text{Na}_2\text{O} + \text{K}_2\text{O} < 10 \text{ wt\%}$) and high lime levels ($\text{CaO} > 15 \text{ wt\%}$) (Dungworth et al. 2006). The glass is probably manufactured using plant ashes, but the exact nature of these has yet to be identified (Dungworth et al 2006). The 17th century glass analysed in this thesis is all of a HLLA composition, this type of glass is known to have been introduced to Britain by continental glassmakers who came to England during the late 16th century (Dungworth et al 2006). A possible reason for the popularity of HLLA glass during the 17th century is due to the ban on the use of wood as a fuel and the subsequent introduction of coal in 1615 (Nef 1966). This meant that wood ash was no longer in ready supply, and had to be specifically brought into the glasshouses, and by the middle of the 17th century glass makers were competing with other trades such as soap makers for the increasingly limited supplies of potash (Tyler & Willmott 2005). Therefore a glass which could be used for the creation of windows and which didn't need large amounts of alkali in the form of ash would have been a popular choice. Table 3-20 is a comparison of the average compositions of the HLLA, Medieval and mixed alkali glass to different types of plant ash.

	SiO₂	Na₂O	K₂O	Al₂O₃	MgO	CaO
Van Linge	59.37	3.07	4.55	3.17	3.11	20.50
Price	59.06	0.95	6.19	2.19	1.95	23.46
Medieval	52.98	2.34	12.44	1.54	7.79	15.24
Mixed Alkali	67.63	8.89	5.13	0.84	2.62	11.13

Kelp		19.63	16.23	0.40	9.40	9.87
Fern	8.00	0.40	25.50	1.50	8.00	18.00
Bracken	25.00	0.50	35.10	0.50	2.30	8.90
Pine		0.06	16.24	0.47	7.03	29.05
Aspen	0.11	0.06	11.27	0.14	3.55	21.17
Poplar		2.30	7.93	0.35	9.09	25.67
Oak		0.08	6.08	0.68	5.20	36.58
Cabbage		0.19	3.23		0.56	0.91
Spinach		0.84	8.87		2.60	2.01
50% Wood 50% Bark	12.73	0.86	6.70	2.82	3.28	39.88
40% Wood 60% Bark	46.85	2.01	22.41	2.25	1.56	11.24
50% Wheat 50% Barley Straw	46.85	2.01	22.41	2.25	1.56	11.24

Table 3-20 Average compositions of glass in this thesis and some common plant ashes. Data relating to Kelp, Fern and Bracken taken from Tite et al 2006; data relating to Pine, Aspen, Poplar and Oak taken from Misra et al 1993; data relating to Cabbage and Spinach taken from <http://njaes.rutgers.edu/pubs/bearreport/table3.asp> all data was converted to oxide wt%; data relating to mixed ash compositions taken from Orlanders and Steenari 1995, all data was converted to oxide wt%.

The high lime contents could be explained in a similar way, for example, certain types of plant ash, such as that from oilseed rape, contain large quantities of sodium, potassium and calcium (Dungworth et al 2006). If the flux for the glass came from the ash of a plant such as oilseed rape, and the glass makers were also deliberately adding lime then this would have a cumulative effect and the lime contents of the glass would be increased. Two types of HLLA glass are identifiable from the compositions of the fragments tested. This means that there is a difference in the raw materials used to produce these two types. With the exception of the coloured Van Linge samples, and sample CCOX30 which is flashed dark red, the Van Linge samples have a higher Na₂O content and a lower K₂O than the Price samples. There are two possible explanations for this, a) the ‘earlier’ Van Linge glass was imported whereas the ‘later’ Price glass was made in England, or b) both types of glass were made in England but using different plant ashes as the fluxing agent. If glass manufacturers were able to get hold of wood

ash for the production of glass, then the temperature and furnace conditions in which the ash had been created would affect the composition (Etiégni & Campbell 1991). For example, as the combustion temperature is increased, the amount of potassium and sodium in the wood ash decreases, while the amount of calcium increases (Etiégni & Campbell 1991). Again, if a wood ash was used as the fluxing agent, and lime was also added separately to the melt, then the effect would be cumulative and result in a higher CaO content. Also, because the Van Linge glass, for the most part, has the higher Na₂O contents of the HLLA glasses, it could be that the Van Linge glass uses a plant ash that is slightly more soda rich than the Price glass which is more potassium rich.

During the 17th century most of the window glass used in England was imported from the continent (France in particular) and during the 17th century, foreign glassmakers were often employed in English glass houses (Buckley 1914a). By the 1670s, the English glass industry was attempting to manufacture a product that could compete with the steady flow of the Continental European imports, including the employment of Continental staff (Tyler & Willmott 2005). One possible reason for suggesting that the glass used to create the Van Linge windows at Christ Church was imported would be because the composition of the HLLA glasses suggests that wood ash would have been used as a flux. As mentioned above the use of wood ash for glass manufacture was restricted in England from 1615, whereas on the continent no such restrictions applied, and a lot of window glass was imported. English statutes of the 17th century show that English glassmakers were directly taxed, whereas the importation of foreign glass wares were not taxed (Buckley 1914b).

There were two periods during the 17th century when tax was imposed directly on glass manufacturers in England, the first during the Interregnum (1649-1660); Cromwell levied a tax on all glass being imported, this was in order to raise funds for the government during turbulent times. The second tax was imposed by William III between 1695 and 1699 in order to raise money for the 'French War'. This latter tax was imposed not only on glass, but also on the raw materials used to create the glass (Buckley 1914b). By the late 17th century English glassware had become a prized commodity abroad and glassmakers were exporting a third of their output, also foreign glassmakers were attempting to hire English glass-men (Buckley 1914b).

Looking at the composition of the Price and Van Linge glasses, it is clear that they have been made using different flux raw materials; this taken in the context of the 17th century glass trade suggests that the observable differences may well be due to one type of glass having been imported. For example, the Van Linge samples have a tight core to the group but also have several dispersed outliers; this could be because the glass is being imported from more than one glass manufacturer. Whereas, the Price samples all group tightly together strongly suggesting that the glass may have come from a single manufacturer, possibly even a single batch. It must be remembered that Price only created one window in the cathedral, which would probably have taken one or two years to complete, whereas the Van Linges created an entire scheme, taking around 10 years to complete. Price did restore some of the earlier Van Linge glass and as was mentioned earlier (section 3.5.1) this can be clearly seen in some of the other college chapels. Some of the fragments that were initially identified stylistically as being the work of Van Linge grouped compositionally with Price. This, therefore, is evidence not only that Price restored some of the Van Linge windows, but that the restorations are potentially detectable on a compositional level.

The evidence shows that no clear order for the creation of the Van Linge windows can be identified based on the composition of the glass alone. One possible reason for the variation in the glass composition is because the Van Linges were importing their glass; another reason could be because they were utilising existing stocks of glass to create the scheme. The brothers were involved in creating windows for many of the college chapels in Oxford and as such would most likely have had glass left over from previous jobs. Therefore, as well as commissioning new glass, they used glass that was already available around the university; this would also have been the cheaper option for glazing the cathedral. A scheme of this size (c.19-22 windows) created over the space of 10 years would have required several batches of glass. The data suggests that the Van Linges were not assigning one batch per window.

The trace elements in the glasses show a similar pattern to the major/minor elements in that in most cases the two groups of HLLA glass can be clearly identified; although, in some cases there is overlap between the groups, for example, with La and Cr, and with Nd and Fe. This suggests that the two glasses may be utilising a similar sand source in their manufacture. This is supported by the fact that the Si contents for

the HLLA glasses are indistinguishable. There are some correlations amongst the trace elements for the Price samples, most notably in terms of Zr and Ti, La and Ti, Nd and Fe, and La and Cr. The correlations in the Price samples are probably indicative of a particular ore source used as a colourant or decolourant, the source of which is as yet unknown.

Although glass painting was quite prolific in the 17th century, coloured stained glass was still in use (Lowe 1975). This is true of the Van Linge work, for example, the figure of Jonah has robes made of stained rather than enamelled glass. The decline in the use of stained glass occurred because of the difficulty in obtaining it combined with the subsequent cost of importing the glass (Lowe 1975). The Van Linges may have imported small pieces of coloured glass for specific areas of the windows; French window glass was particularly popular during the early 17th century (Turnbull 2001). Alternatively, they could have been recycling existing stained glass; certainly during the 1640s glaziers are encouraged to re-use old glass as much as possible even when working on royal palaces (Turnbull 2001), therefore, a cathedral would not necessarily discourage the practice of using recycled glass. Another possibility, which may begin to explain why the Van Linge samples of coloured glass have some similarities with the Price glass is the possibility that broken glass (cullet) from England was exported to the Continent and subsequently used in the production of coloured glass, which the Van Linges later imported. The collection of broken glass to sell to glass houses was a practice that kept many poor people fed and watered, and the export of broken glass brought in enough of a revenue that during the 17th century these exports were also taxed (Buckley 1914b). Another reason for supposing that the coloured glasses in particular were imported from the Continent is because there are very few records and subsequent evidence of 17th century coloured glass working in Britain (Tyler & Willmott 2005; Dungworth et al 2006), the exception being the production of green glass and the use of manganese to decolourise glass.

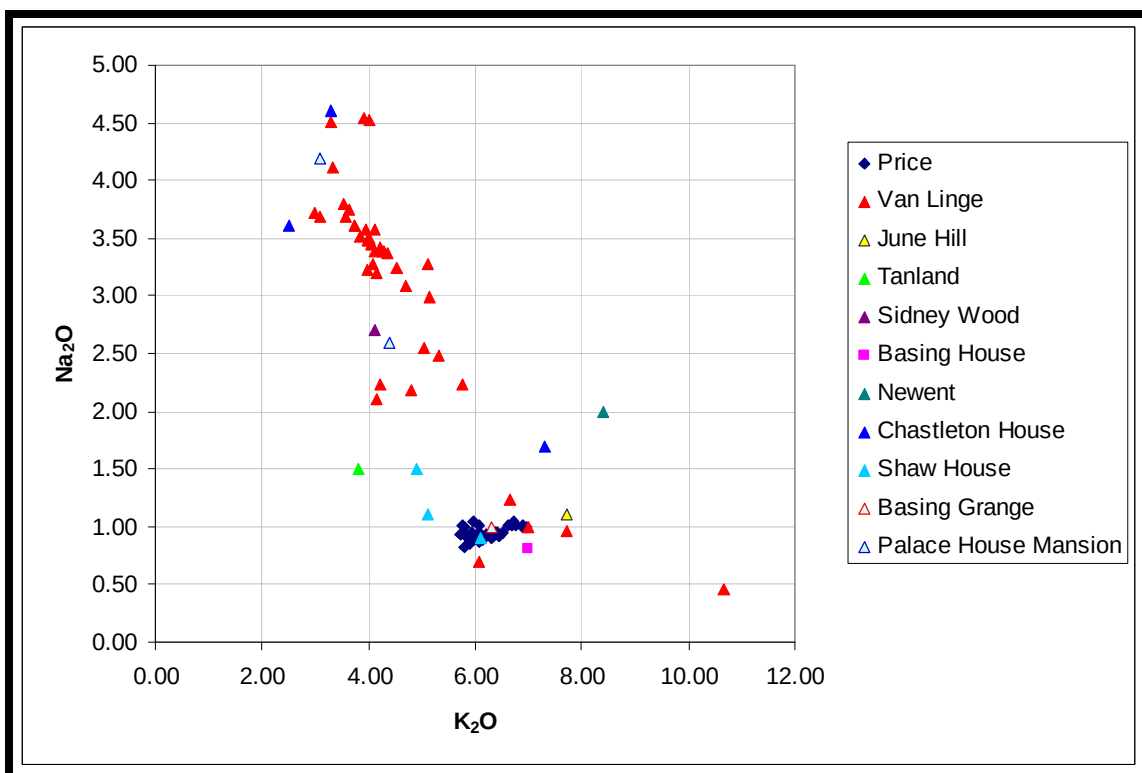


Figure 3-78 A comparison of Price and Van Linge glass with other 17th century glass based on Na_2O and K_2O (wt%) contents

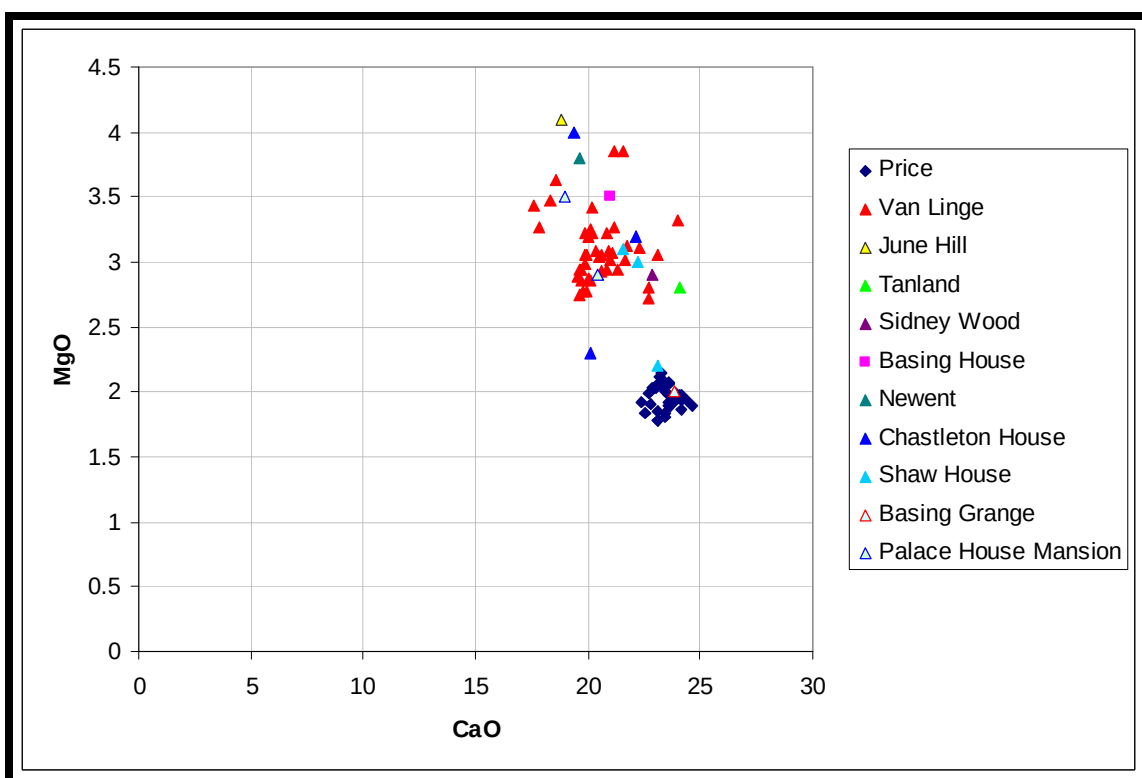


Figure 3-79 A comparison of Price and Van Linge glass with other 17th century glass based on MgO and CaO (wt%) contents

By comparing the Christ Church HLLA glass with other 17th century window glass from around the UK (courtesy of David Dungworth) it can be seen that one sample from Shaw House and the sample from Basing Grange appear to plot closely with the Price samples (Figure 3-78 and Figure 3-79). But, all of Dungworth's samples are dispersed between the Price and Van Linge groups, and therefore no meaningful relationship can be drawn between them. It is interesting to note that in terms of Dungworth's samples taken from a single location i.e. Chastleton House or Palace House Mansion, the glasses sampled still produced dispersed results. This suggests that either the windows sampled were of different 17th century dates or came from different manufacturers. Unfortunately, these comparisons do not help answer the question of where the glass in Christ Church was manufactured. On the other hand, a comparison of the 17th century glass from Christ Church with three samples of 1st century BC-2nd century AD glass from Soulac-sur-mer, La Négade, Gironde, France (Henderson 1988), show some interesting compositional similarities (Figure 3-80, Figure 3-81 and Figure 3-82).

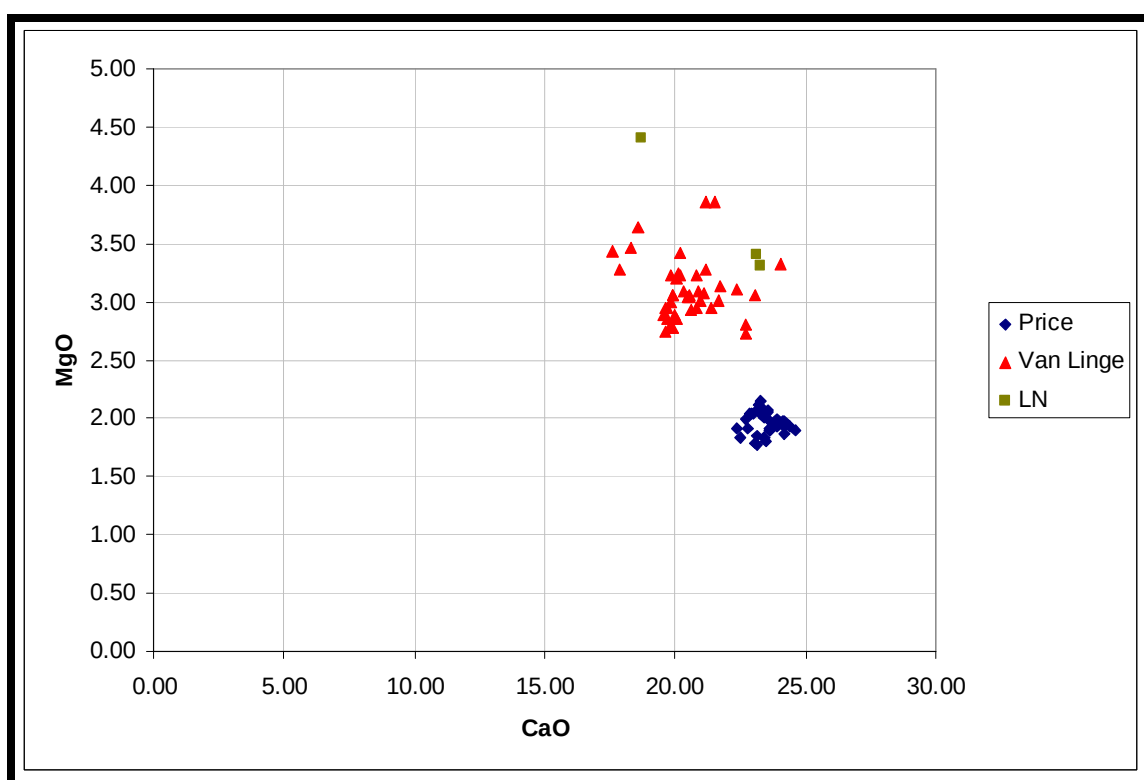


Figure 3-80 A comparison of Price and Van Linge glass with samples from La Négade based on MgO and CaO (wt%) contents

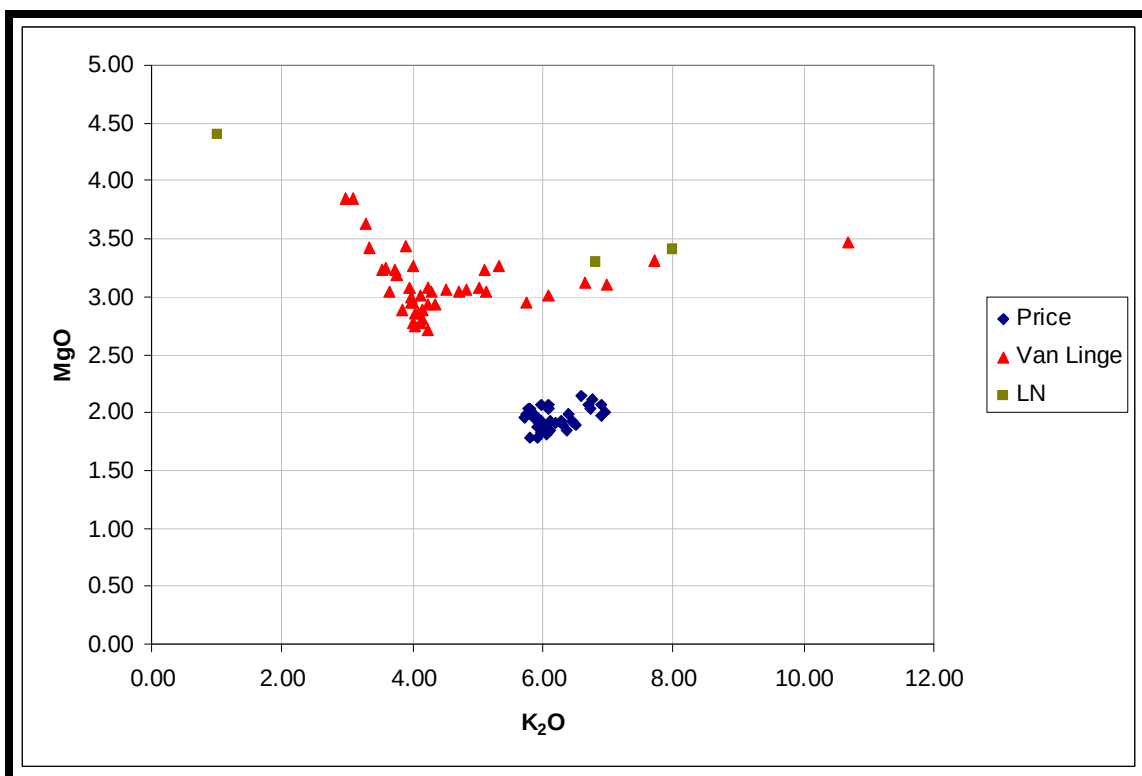


Figure 3-81 A comparison of Price and Van Linge glass with samples from La Négade based on MgO and K₂O (wt%) contents

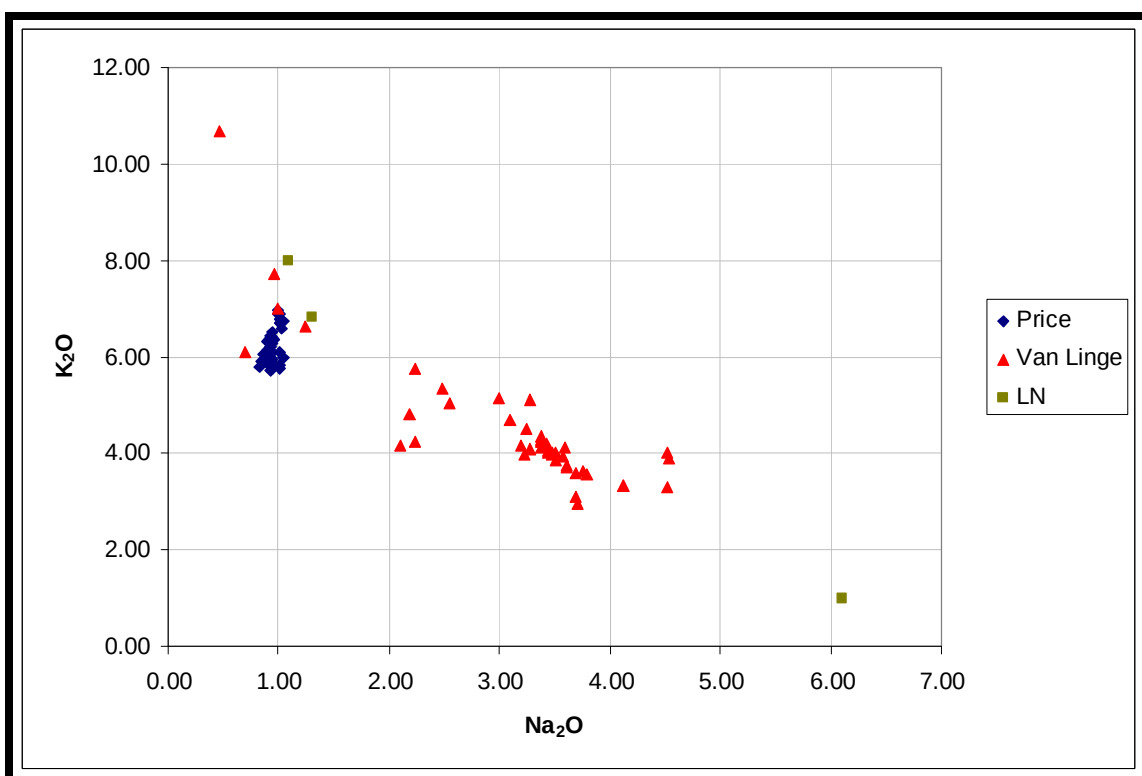
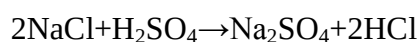


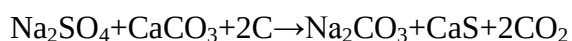
Figure 3-82 A comparison of Price and Van Linge glass with samples from La Négade based on K₂O and Na₂O (wt%) contents

Henderson says these samples are ‘mixed-alkali’ glasses, but the alkali, lime and magnesia contents are indicative of HLLA glass. Two of the samples, in particular, group with the Van Linge coloured samples from Christ Church. Henderson said that the K₂O contents of these glasses was highly variable suggesting the use of a highly variable alkali source. He also suggested that the La Négade glass was derived from a wider ‘catchment’ area rather than raw materials from a single site (Henderson 1988). Henderson (1988) suggests that the La Négade glass probably used a potassium rich plant ash, such as wood ash or fern as a flux, but argued that the sample with higher Na₂O probably also used a maritime plant ash. This comparison of Henderson’s early glass with the glass from Christ Church suggests that the Van Linge glass was probably made using wood ash and is likely to have been imported from the Continent, in particular France.

The Victorian samples are all low in K₂O and high in Na₂O, this is because most of the Victorian glass will have been made using synthetic soda. The Leblanc process for the creation of soda from salt was developed in 1789 by Nicolas Leblanc and patented in 1791, a French chemist and surgeon (Sutton 2006). Alkali is a vital component of glass, and as mentioned earlier, the source of the alkali in the form of wood ash was harder and harder to obtain. Glass manufacturers were in competition with other industries such as the soap makers who also utilised ash for industrial manufacturing processes. British and French chemists searched for ways of producing alkali cheaply from local sources, and in 1783 the Paris Académie Royale des Sciences offered a prize for the most satisfactory method of achieving this (Sutton 2006). Leblanc’s process was voted as the best method. The first step of the process involved heating common salt with sulphuric acid to produce salt cake (sodium sulphate) and hydrochloric acid:



The salt cake was then roasted with limestone/chalk and coal/charcoal to produce a solid known as ‘black ash’. This ‘black ash’ consisted of soda ash, calcium sulphide, and unburnt coal:



The soda ash could then be washed out of the ‘black ash’ with water (Keifer 2002). The success of this process hinged on the addition of calcium carbonate or limestone to the reaction (Keifer 2002). During the 19th century Britain was producing more than 70,000 tons of soda ash per year utilising the Leblanc process. This made Britain one of the dominant chemical manufacturers in the world. The problem with the process were the large quantities of hydrochloric acid and calcium sulphide produced (Keifer 2002). This technique for synthetic soda was later superseded by the Solvay Process developed by the Belgian, Ernest Solvay, in 1863. The new process was less expensive and less complicated, producing soda and the by-product calcium chloride (Killefer 1945). The high Na₂O and low MgO contents of the Victorian glasses is therefore, indicative of the use of synthetic soda in their manufacture.

One of the Victorian samples CCOX123 has a low Na₂O content (5.66 wt%) and high K₂O content (12.91 wt%), and in many respects has similarities with the Medieval sample (CCOX102), but the MgO content is the same as the other Victorian samples (0.08 wt%), this sample also has a very low CaO content (2.78 wt%). The lack of CaO to a certain extent can be balanced by the PbO content at 4.27 wt%; this would provide the glass with c.7% of stabiliser. Henderson (1988) had similar ‘unexpectedly’ low CaO and MgO contents in three of his 9th-7th century BC mixed alkali glasses from Rathgall, Ireland, he said this *“is a feature for which it is difficult to find parallels amongst prehistoric and other glass compositions”* (Henderson 1988: 81). All of the Victorian glasses form a dispersed group and sample CCOX123 is the most extreme outlier of this group. CCOX123 is unusual in that it has almost 20wt% alkali, the majority of this being potassium rich. A possible explanation for this glass would be the idea of recycling. CCOX123 is a light blue glass, and may have been created using Medieval pot metal blue glass as cullet. If blue high potassium glass was added to a melt as cullet, maybe to impart the blue colour to the new glass, and the melt used a soda flux, then this may explain the high level of alkali in the glass. An analysis of the trace elements of this sample would be able to shed more light on the possibility of the sample using potassium cullet in its manufacture. Including CCOX123, four of the Victorian samples contain lead, CCOX123 has the most at 4.27 wt%; while CCOX25, CCOX27 (both flashed red) and CCOX29 (Green) all contain between 2.53 and 3.37 wt% PbO.

Sample CCOX102 identified as a sample of medieval glass from one of the Latin Chapel windows has a high K_2O content and a low Na_2O content, it also has a very high MgO content at 7.79 wt%. This composition is what would be expected from a glass made from potassium-rich ‘inland’ plants typically found in the UK and Northern Europe. Medieval glass is also often referred to as ‘forest glass’ because the flux material is usually derived from forest based plants. Forest glasses are usually green in colour, due to the iron impurities in the raw materials (Dungworth et al 2006), this sample is colourless and has had manganese added in order to attempt to counteract the iron.

Samples CCOX02, CCOX03, and CCOX05 form a group of three samples which as yet are of unidentified origin i.e. it is not known from which window these samples originated. All three of the samples are colourless with no obvious painted decoration, and so cannot be attributed to a specific artist or art-historic period based on stylistic grounds. These samples appear to have more of a mixed alkali composition, with c. 9 wt% Na_2O and c. 5 wt% K_2O . Mixed alkali glasses occur in Britain from the mid-17th century until the mid-19th century, but they are particularly associated with early 18th century (Dungworth 2007 pers. comm.). This means that without further data it is extremely unlikely to be able to attribute these samples to any particular artist, although it can be tentatively said that they date to the early 1700s based on the composition. If these glasses are from the early 18th century, then they could tentatively be attributed to Oliver. If this is the case, then it shows that the three main glass painters at Christ Church during the 17th century, Van Linge (1640s), Price (1696) and Oliver (1700), who are working within a relatively short period of each other, are all using completely different compositions of glass. This could be because different glass manufacturers from different areas of the country (or continent) are providing the glass, or because different glass manufacturers were experimenting with different recipes and raw materials. As Henderson (1988) suggested, the ‘mixed-alkali’ glass could represent a transition glass, either between different periods of history as different raw materials are available or possibly between different technologies.

A potential source of flux which could provide a ‘mixed-alkali’ signature is the use of kelp. Kelp was produced from seaweed (that which had washed ashore from the deep ocean as well as rock-growing weed); after the weed was dried it was burned

slowly in kilns, trenches or pits near the shore. This process produced a molten mass which was stirred until it had fused; after c. 2 days it became a solid mass, which was cooled and broken into lumps, ready to be transported to the glasshouses (Turnbull 2001). The quality of the kelp varied greatly but a good kelp contained 15.1-21.95% K_2O and 2.55-16.85% Na_2O , although in a bad kelp these figures could be greatly reduced (Turnbull 2001). Alternatively the ‘mixed-alkali’ glasses could have been created by the addition of a mixture of plant ash from different sources, i.e. terrestrial and marine.

The RIs of all but the ‘mixed-alkali’ glasses were determined along with examples of Egyptian and Roman glass. This was in order to see whether a technique used routinely in forensic glass analysis could be applied to archaeological samples. A RI was accurately recorded for all bar the 17th century glasses (both Van Linge and Price). The results showed differences in RI between samples of the same age, but this was not unexpected, due to the variability of the raw materials and the recipes used in the manufacture of the glass. It was interesting to note that the 17th century samples had very high RIs (so high that it was not possible to accurately determine their exact RI with the available facilities). The Medieval sample also had a high RI at 1.55049; this sample and the 17th century samples both had high CaO contents (>15 wt%). The two Roman samples PD26 and PD29, along with CCOX123 had the lowest RIs, and these samples all had relatively low amounts of CaO. Therefore, it is likely that the lime content of the glasses is one of the most influential factors in determining the RI of the glass. Heavy elements are also known to have a greater effect on the optical properties of glasses (Dararutana & Sirikulrat 2007) for example, quantities of lead or barium will also raise the RI. CCOX123 has a very low CaO content but it also has a quantity of PbO present, thereby giving a higher RI.

Sample	CaO (wt%)	PbO (wt%)	RI
COP9			1.52163
UPP3			1.53137
PD26	5.18	-	1.51270
PD29	6.18	-	1.51775
CCOX102	15.24	0.05	1.55049
CCOX123	2.78	4.27	1.51905
CCOX01	13.08	0.07	1.52944
CCOX103	13.10	0.02	1.53101

Table 3-21 Comparison of RI against CaO and PbO contents of the glass samples

This raises the question of whether RI analysis could be used as a screening technique for archaeological glass samples. This would assume that certain types of glass had specific compositions and that those compositions were fairly uniform, for example, 17th century glass is HLLA. But, problems would occur when comparing, for example, Victorian glass and Egyptian glass, as can be seen in Table 3-21. It would therefore depend on the circumstance of the screening, for example, if using the method within a cathedral environment such as Christ Church, it is possible that Medieval could be distinguished from Victorian. If the screening technique were to be used to determine Victorian glass forgeries from genuine Egyptian pieces, for example, it may be harder to prove whether the samples were original or Victorian fakes based solely on the RI. But, more analysis into the use of RI for archaeological glasses could be productive.

3.14 The 'Jonah' Window, Handheld X-ray Fluorescence (HH-XRF) Analysis

Following the analyses of some of the fragments from Christ Church Cathedral and the successful grouping of those fragments into specific art-historic periods and in some cases the identification of the work of specific artists; it was decided to attempt to see if this work could be used in-the-field. Was it possible to use a portable analytical technique to differentiate between the different compositions of glass and if so, was it possible to use this technique on the in-situ windows in the cathedral? The idea would be to determine which sections of the window in question were original and which panes were later replacement sections. This research would not only be a novel use of a relatively new piece of technology, but it would also show the usefulness and practical outcomes of the research undertaken for this thesis. For example, if, through a combination of the research completed on the Christ Church fragments and an analysis of the in-situ windows, areas of the windows that are original and areas that are restorations can be distinguished, then it will be possible to determine the best way in which to conserve the windows should further work need to be undertaken. It has been shown in this thesis that various people over the years have restored the work of previous artists. These various restorations have in themselves become part of the history of the windows and would therefore need to be treated sympathetically in terms of preserving the antiquity and interest.

As mentioned previously (section 3.10.2) the window has had several locations within the cathedral, and the current location of the window was not where it was originally intended to reside. This can be seen in the way the painted image does not fit the window space properly (Figure 3-83).

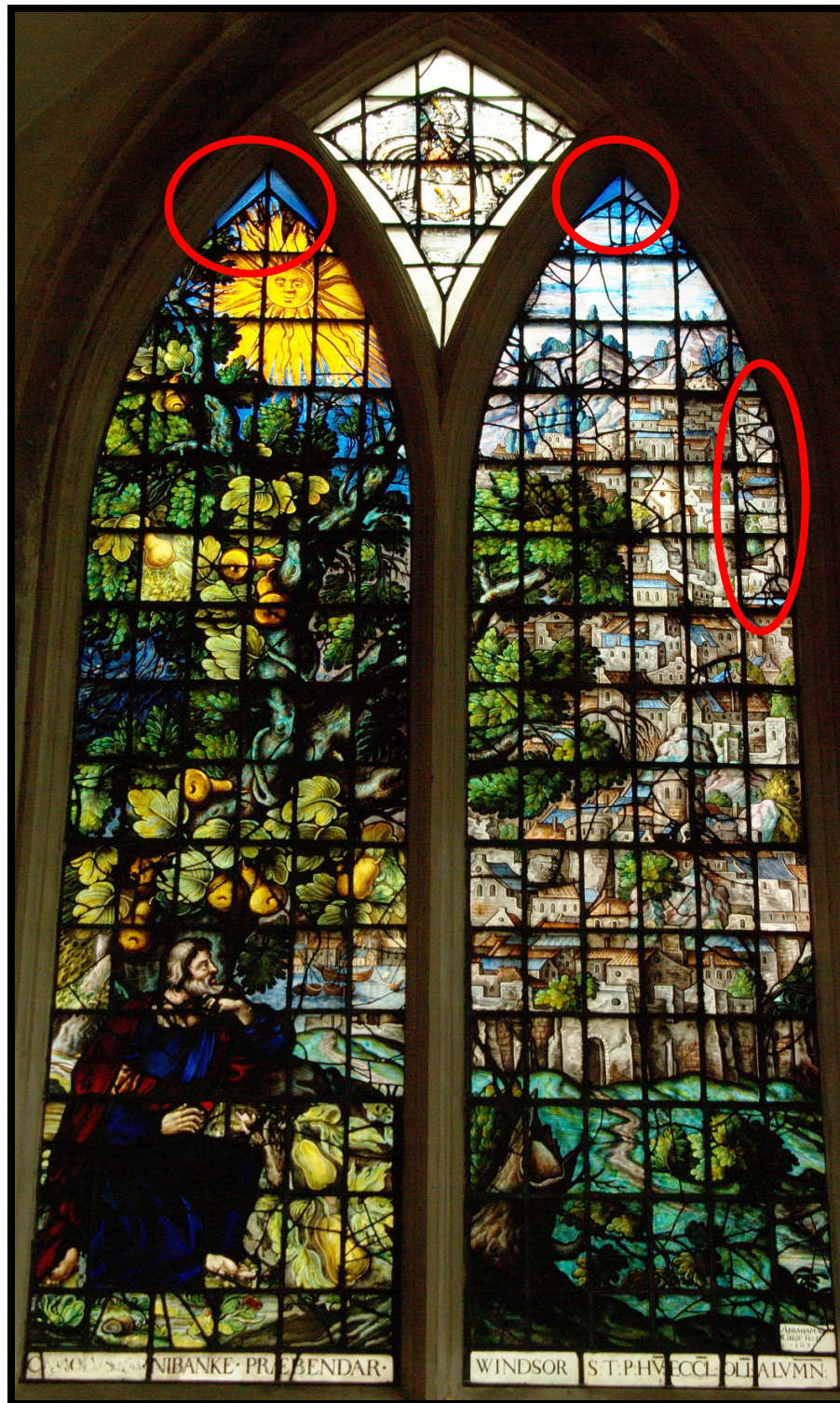


Figure 3-83 'Jonah before Nineveh' highlighting where the window does not fit properly (Image courtesy of J. Rogers 2010)

A look at the window space in which the glass was located immediately prior to its current location, will show the difference in size and shape of the two windows. After the removal of the 'Jonah' window the architecture of the window was changed

from Y-tracery to Perpendicular in style. Aside from this, the actual window size was wider than the current 'Jonah' space, and as Figure 3-83 shows, the pointed arches were probably also shorter. The original window shape can be projected from painted apex in the window, showing that the 'Jonah' window would have been 'cropped' to fit the current space. In terms of the right-hand light, this would have been a fairly easy task, i.e. only pieces of city, or tree would have to be removed. This hypothesis is supported by the small slithers and badly fitting panes on the right-hand light. The left-hand light would have been more challenging, although pieces of foliage etc could have been removed, Jonah would have been an issue. For example, Jonah would probably have been located in the lower left hand corner, but in order to fit the image into the current space he would probably have had to have been moved to the right. This hypothesis can be supported, by looking at Jonah's feet and the foot of his robes. Jonah's right foot, is in fact someone else's left foot, and the centre panel of his robes is longer than either of his feet. This suggests that the figure of Jonah has been heavily restored. The abrupt ending to Jonah's robe suggests that either a) this part of painting is a later restoration, or b) the figure of Jonah was originally larger than that which remains today. Apart from his head (and feet), Jonah is leaved, this would mean that to a certain extent the figure can be moved.

The section of tree to the left of Jonah is also a later insertion, because the original Jonah tree is the large section of dark green trunk which can be seen above the prophet's head. This tree stops abruptly to the left of Jonah, and has been replaced with a different painted tree. To the right of Jonah's right hand is a section where the top of a rock appears in the foreground of a footpath. The Lower part of this rock is missing and instead there is a gourd bush. If the pieces of glass depicting the rock and footpath are later additions, then these pieces are not part of the original Nineveh, which raises the question of which city wall is this footpath leading up to? The gourd bush and lower landscape surrounding Jonah are of a different style to the rest of the window and are probably later additions, but whether they represent restoration to the window completed by Price at the end of the 17th century, or whether it is an addition from the 1870s when the window was moved and adjusted to fit this space remains to be seen.

The section to the right of Jonah depicts part of a city and some boats on the water; this also appears to be an insertion from another window. The right hand pane

appears to depict part of a city on fire with a boat being capsized in the foreground. The pane to the left of this appears to depict the same city, and it can be argued that the dark background behind the houses is smoke. In both panes the level of the water appears to be rising up the sides of the buildings. This strongly suggests that this cityscape is not part of Nineveh, but is in fact part of the destruction of Sodom and Gomorrah. The pane to the left of these which appears to depict part of a large leaf overhanging water is the only pane which contains the leaf matter from the gourd tree and the water from the cityscape. It will be noted that this pane has leading running across where at one point it was probably broken. A reasonable explanation is that when the window was being adjusted to fit the new space, the figure of Jonah was moved to the right, and the left hand light needed to tie in with the right hand light, and so a piece of city was inserted. The artist then painted a new pane depicting both leaf and water to tie the two pieces together. This may also explain the insertion of the city wall and footpath immediately below the boats, the corresponding scene on the right hand light is the city wall. Figure 3-84 highlights these potential alterations.

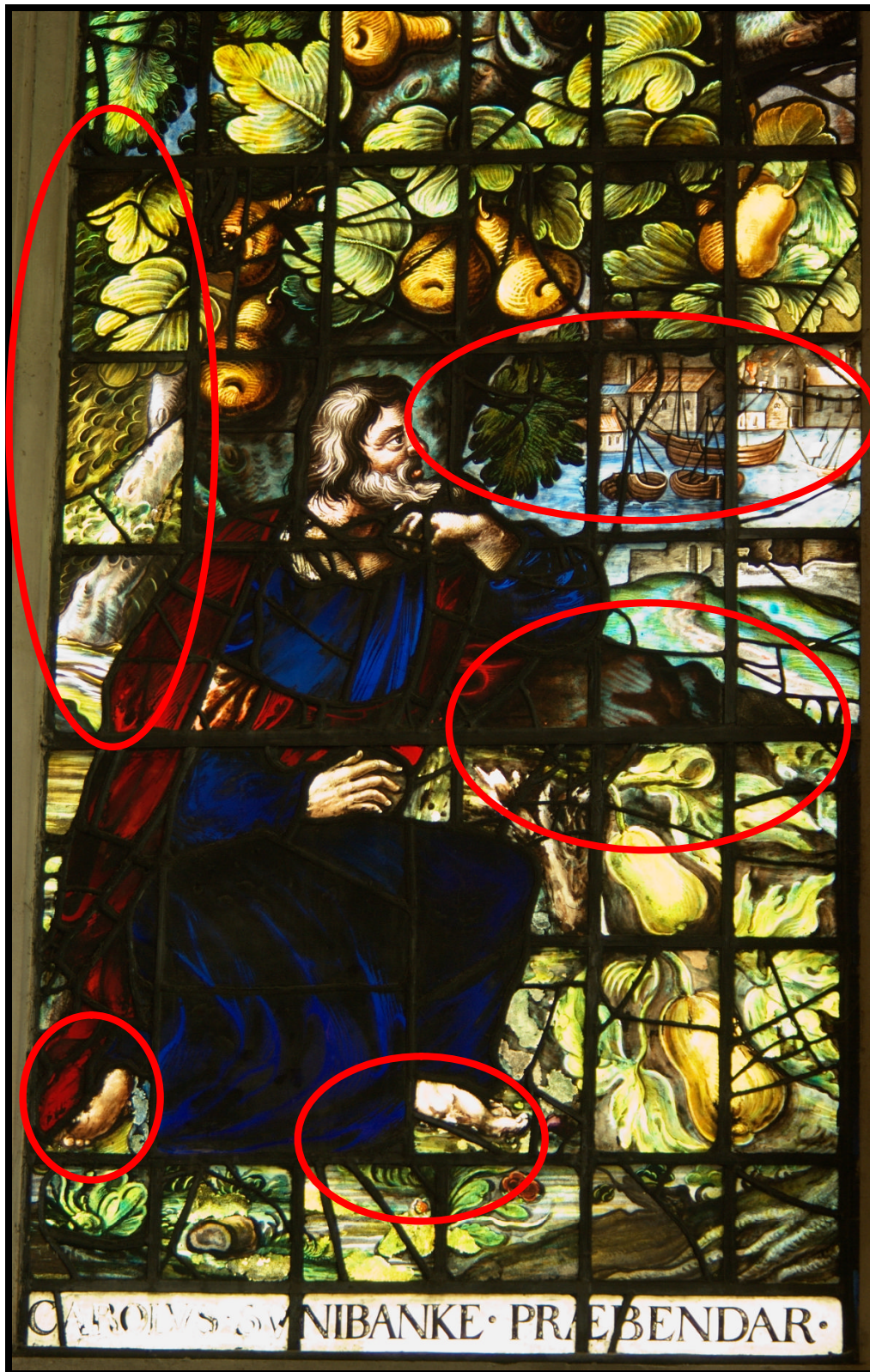


Figure 3-84 Alterations in the 'Jonah' window (image courtesy of J. Rogers 2010)

The window was adjusted to fit a new space, but, it has also received a certain amount of restoration over the years and references to this have been made by the 19th

century authors. These restorations become particularly obvious when looking some of the depictions of the gourds.

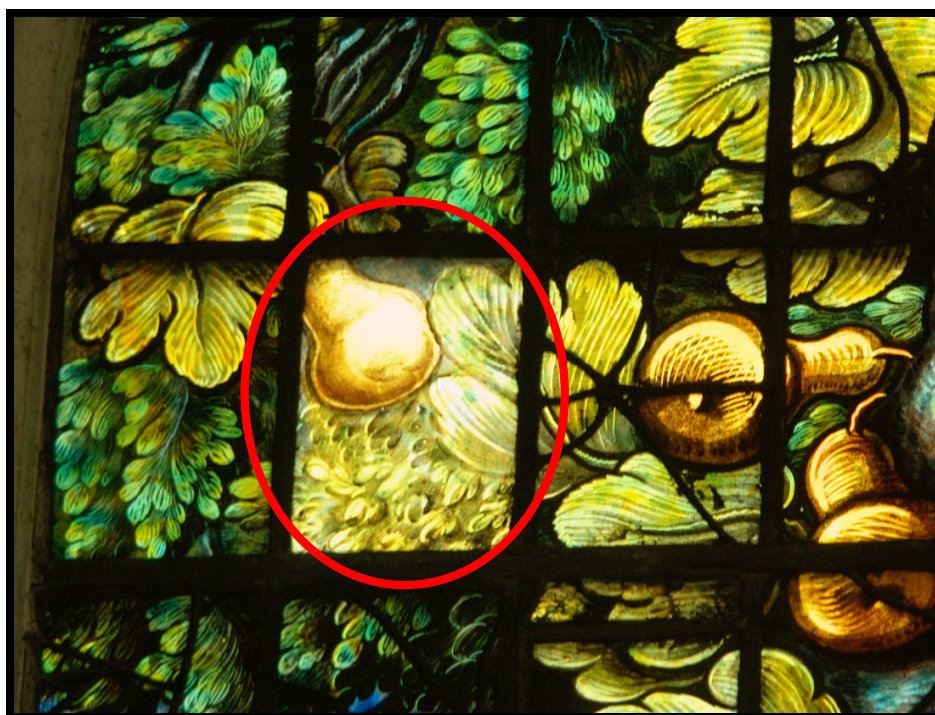


Figure 3-85 Restored gourd in 'Jonah' window (image courtesy of J. Rogers 2010)

In Figure 3-85 it can clearly be seen that not only is this gourd a different colour to the surrounding ones, it is painted in a completely different style. A black and white photograph of this window dated to the 1980s shows some blank areas where repair was needed. This photograph is currently in the care of the vergers of Christ Church.

Despite the relatively recent restorations to this window, it is even now in need of some repair, for example, areas towards the top of the window on both lights are beginning to flake (Figure 3-86), and on the right hand light someone appears to have stuck 'sticky tape' to the pane (Figure 3-87)!



Figure 3-86 Left hand light showing the flaking paint



Figure 3-87 Right hand light showing sticky tape

The final part of this window is the crest and coat of arms in the top centre light (Figure 3-88). The arms consist of a red shield with three silver semi-naked men carrying gold clubs over their right shoulders; between the upper two men is a gold crescent. The crest above the shield is another slightly larger semi-naked man carrying a club over his right shoulder (Figure 3-89). Gutch (1786) assigns this coat of arms to Wood; “Wood. *Gules, three Demi Savages Arg. holding Clubs over their right Shoulders Or; a Crescent for difference Wood. Crest – a demi-Savage, as in the Arms*” (Gutch 1786: 464). Further investigation has shown this to be the arms of Basil Wood (Allen 1912), who donated one of the painted windows in Christ Church. According to

Anthony Wood (Wood quoted in Gutch 1786) Basil Wood was a Fellow of All Souls College and afterwards Chancellor of St. Asaph and Rochester, and eventually of Oxford. It is at present unknown which painted window he donated to the cathedral.

The crest and arms have also been damaged; a section between the crest at the top and the shield below appears to have been replaced with random pieces of coloured glass, probably from other pieces of heraldry (Figure 3-90). As with the rest of the Jonah window, this coat of arms does not fit the window space properly (Figure 3-88).



Figure 3-88 Wood coat of arms in Jonah window (image courtesy of J. Rogers 2010)



Figure 3-89 Arms of Basil Wood (Horsfall Turner 1911: 21)



Figure 3-90 Closer detail of the Wood coat of arms (image courtesy of J. Rogers 2010)

When Gutch (1786) describes the Jonah window he also describes the arms of Sunibanke as being present. “*Sunbanke. Arms – Azure, a Chevron Or between three Suns Proper. Crest – a Lamp Proper*” (Gutch 1786: 464). In other words, a blue shield with a gold arrow (chevron) with three suns (presumably two above and one below the chevron). The term ‘proper’ means that the suns are naturally coloured, so presumably yellow or orange. The crest above the arms is a natural looking lamp. Therefore, originally the window would have had the arms of Charles Sunibanke in the centre light. It remains to be seen whether pieces of this coat of arms still survive amongst the glass fragments either in the cathedral windows, or in the large collection housed by the

cathedral. The survival of this coat of arms would be dependent on when the Jonah window was moved and whether the whole window was moved or just the pictorial lights. For example, why move more glass than is necessary? If at the time the windows were moved, the heraldry may not have been seen as important, and therefore, the arms of the donor may not have been moved with the window they donated.

3.14.1 HH-XRF

Fragments of glass from the collection at Christ Church Cathedral were examined both visually and scientifically; from this work it has been possible to assign the fragments to groups. Each group has been identified as being the work of a specific artist or dating to a specific art-historic period. This thesis has shown that if the fragments are sampled and analysed in a laboratory they can be assigned to an artist and in some cases a specific window, for example, Price only made one window in the cathedral. The next step was to use a technique that could be utilised in the field to determine which groups the fragments belonged to i.e. no need for sampling, and removal to the laboratory. This technique could also be used to study the in-situ windows still within the cathedral itself. Such a technique would need to be non-destructive in nature if it were to be used on the in-situ windows, but the development and use of this technique would mean that not only could the in-situ windows be studied but the fragments could also be analysed non-destructively thereby further protecting the collection. A Handheld X-ray Fluorescence (HH-XRF) was used to attempt to characterise some of the fragments in the collection at Christ Church, once the accuracy of the machine had been verified against the data collected by the SEM-WDS analyses of some of the fragments, the HH-XRF was used on the 'Jonah' window in Christ Church.

The HH-XRF was used on the reverse of the 'Jonah before Nineveh' window (Figure 3-91) because the HH-XRF is a surface technique and if used on the front of the window would have only detected the enamels. The reverse or 'glass' side of the window had also been back-painted (Figure 3-92), this was in order to give the image on the front depth and in some cases a three dimensional feel. A study of the reverse of the window indicated a number of panes which are believed to be modern restorations rather than 17th or early 18th century work. These were easily identified as they lacked

any back-painting although from the front the work appears very similar in style to the original i.e. a good restoration.



Figure 3-91 Photograph of the rear of the 'Jonah' window at Christ Church



Figure 3-92 Close-up of the back-painted rear of the 'Jonah' window, on the left of the image can be seen a panel which is suspected to be a 'modern' restoration and the city is not back-painted

The machine used to acquire the in-the-field data was a Handheld X-ray Fluorescence (HH-XRF), the Oxford Instruments XMet 5100. The HH-XRF is capable of detecting the elements from Mg to U; it is therefore suitable for light element detection. It is a very fast and precise way of measuring the elemental composition of glass in the field. The HH-XRF was first tested on fragments of glass from the collection to ensure that the measurements were accurate and in line with the existing results. The technique was then used on the 'Jonah' window. A section of glass on each pane was cleaned and then analysed with the HH-XRF for 30 seconds. The XRF runs analyses at 15kV and 45kV. The data collected in the field was compared with the SEM-WDS data for the fragments analysed previously (Figure 3-93 and Figure 3-94).

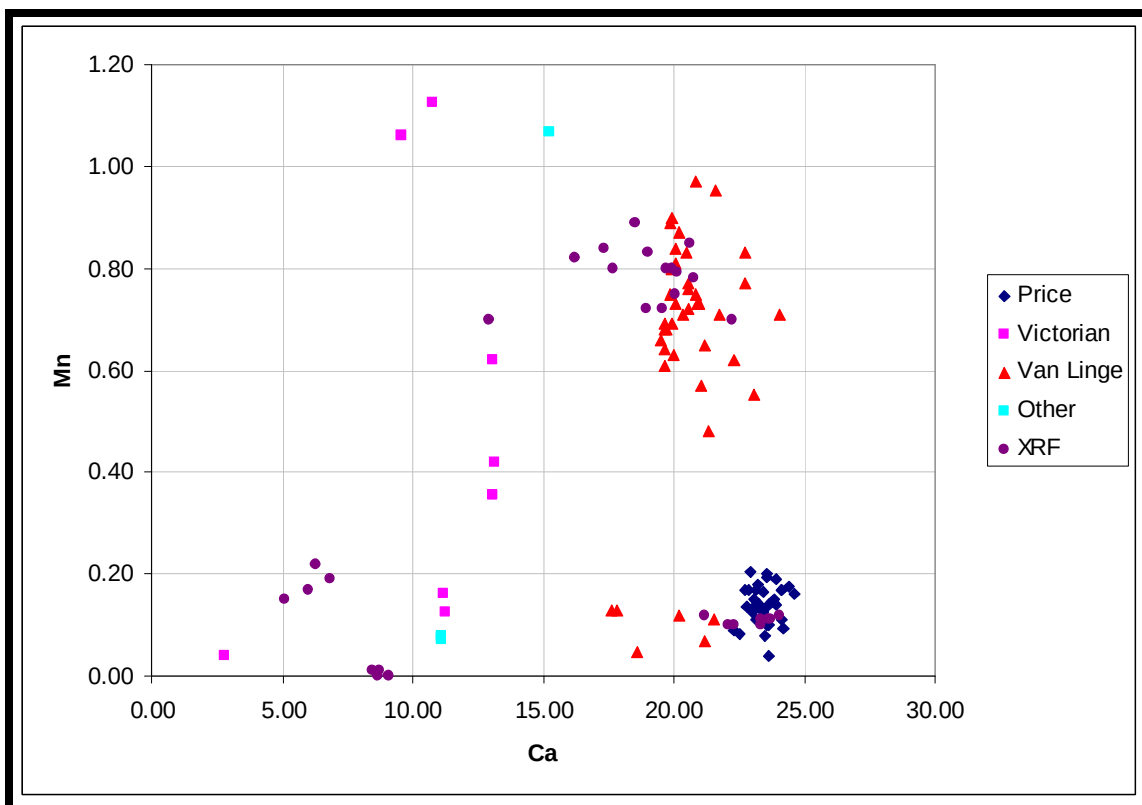


Figure 3-93 Plot of XRF data against WDS data (wt%) for Mn and Ti

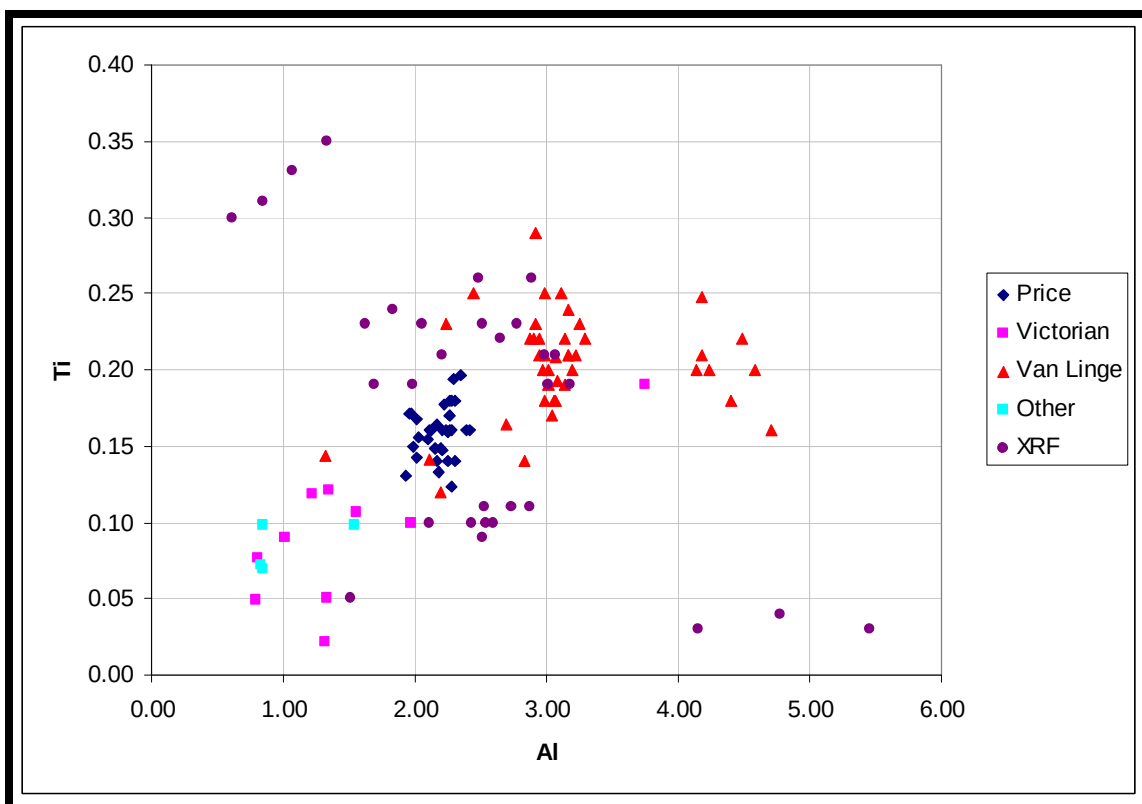


Figure 3-94 Plot of XRF data against WDS data (wt%) for Ti and Al

The XRF data showed good agreement with the WDS data, especially in terms of Mn and Ca. The Price and Van Linge groups could clearly be differentiated, along with the modern panes. The best elements for distinguishing between the glass types while in the field are Ca and Mn; in the 17th century glasses the Ca is higher than 12.5%. The Price glasses have the highest Ca usually over 21%, and have a Mn content around 0.1%, while the Van Linge glasses had the lower 12.5-21% Ca and higher Mn at >0.7%. The reason these groups are broader for the XRF than for the WDS is because the XRF is a semi-quantitative technique, and therefore the numbers are less accurate. Despite this, there is enough accuracy and differentiation between the groups to determine the 17th century glasses from the modern glass and in some cases between the 17th century glasses themselves. The modern compositions of glass can also be separated into two groups, Victorian and Modern (c.1980).

Once the different compositions of glass were determined, they could then be plotted on an image of the Jonah window to determine which panes of glass were replaced or restored and when (Figure 3-95 and Figure 3-96).

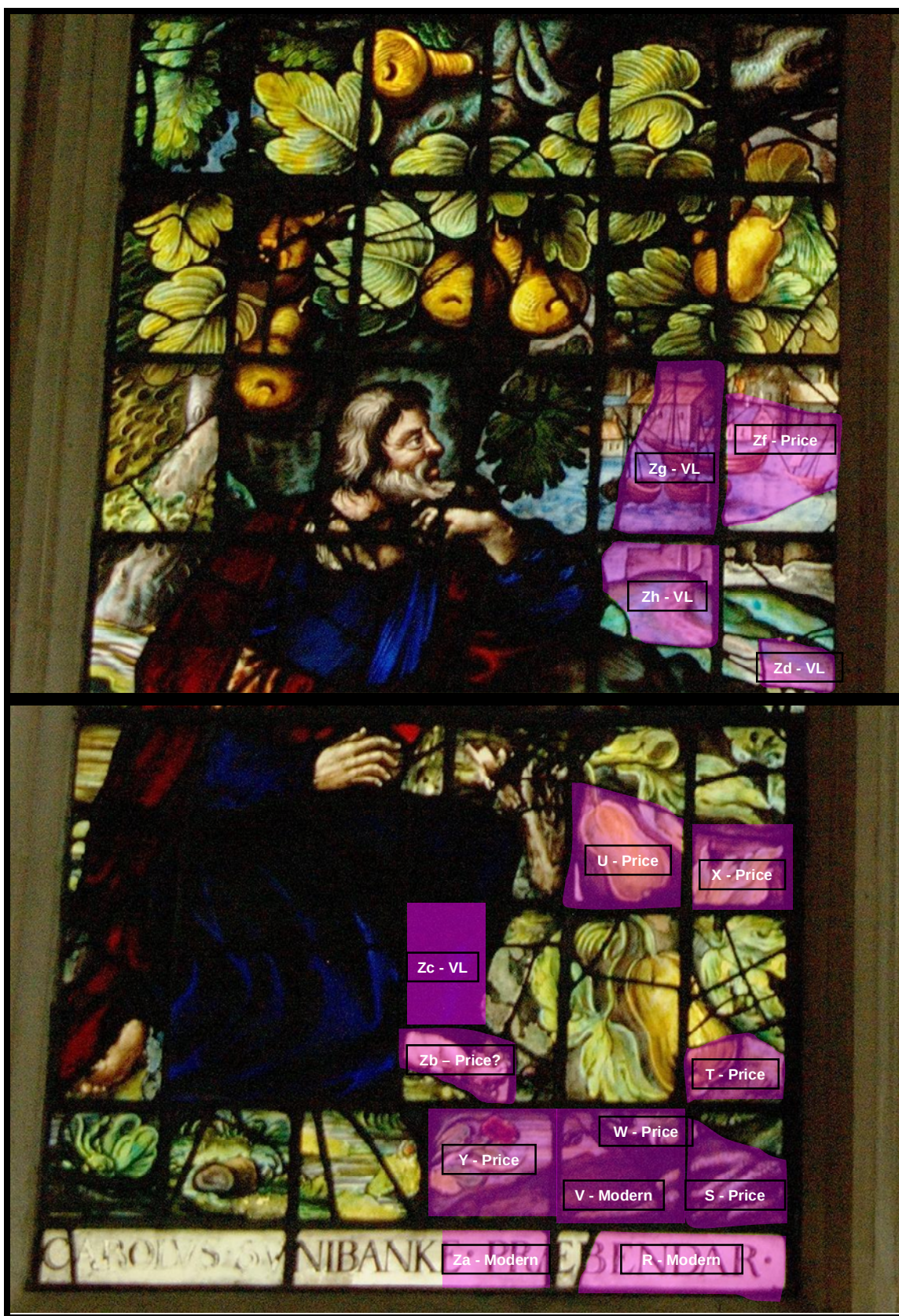


Figure 3-95 Left hand light of the ‘Jonah before Nineveh’ window with the XRF tested panes marked



Figure 3-96 Right hand light of the 'Jonah before Nineveh' window with the XRF tested panes marked

A study of the images on the analysed panes of the left hand light of the Jonah window is interesting, if the XRF data is coupled with the art-historic interpretation of the window, then it can be seen that most of the area surrounding the figure of Jonah has been replaced. Much of the restoration work appears to be by Price, but, with the exception of the text along the bottom of the window which is modern and three panes of Van Linge work depicting boats and an edge of cityscape leading to the water. This section of the painting, is thought by the author to have come from a different Van Linge window. The pane next to this with the boat apparently capsizing and what appears to be flames in the city, turned out to be the work of Price. It is probable that these images were originally in the 'Sodom and Gomorrah' window, Price restored the surviving Van Linge windows when he created the east window in 1696. Price restored the 'Sodom' window including showing the city on fire and the boats in the harbour capsizing, and later when the 'Jonah' window was moved to its current location in 1870s (at the same time the other remaining Van Linge windows are removed) any damage to this window was repaired with suitable sections from the 'Sodom' window. By plotting the XRF analysed glass along with an art-historic critique of the glass a plan of the window can be built depicting which sections are original, which have sections originated in a different window, and which sections are restorations. As well as this it is possible to determine when some of the restoration occurred, i.e. 17th century by Price, or later Victorian/Modern alterations (Figure 3-97).

As mentioned previously, most of the restoration work occurs around the figure of Jonah. The large amount of Price work suggests that the initial restoration of this part of the window occurred around 1696 when Price was known to have been working in the cathedral. The 'modern' work in this area and the insertion of Van Linge and Price work from another window is most likely to date to the 1870s when the window was moved to this location. This is also the time that the surviving Van Linge windows were removed from the building and stored, before finding their way into the coal bunker as fragments. The 'modern' and heraldic work at the apex of the window is also likely to have occurred at this time. The rest of the 'modern' restorations could date to any period of the Victorian era onwards. Some is definitely from the 1980s as is indicated by the black and white photograph held in the cathedral records, showing spaces where repair work needed to be undertaken.



Figure 3-97 The 'Jonah' window showing the locations of different compositions of glass based on XRF and art-historic analysis. From another Van Linge window, Price (1696), Victorian/Modern

This analysis raises questions about the legitimacy of the image of Jonah. Price made a considerable number of repairs to this area of the window (areas with red

question marks are possible Price restorations, but these sections are pot metal rather than colourless and therefore posed problems with the interpretation of the HH-XRF data and would need more investigation). In section 3.14 one possible reason for these changes to the window was given, and that was based on the idea that to fit this window into the current space, the image had to be ‘cropped’ to fit, i.e. Jonah had to be moved further into the window. As the new interpretation shows, the majority of the changes occurred c.1696, before the window was moved to its current location.

Why is Jonah, with the possible exception of his face, not an original Van Linge image? The answer to this can be found in the cathedral records. A passage written in the Chapter Meetings dated June 2nd 1651 stated “*Ordered then by the Dean and Chapter that all Pictures representing god, good or bad angells or Saints shall be forthwith taken down out of our Church windows, & shall be disposed for use in mending of the Glasse that is out of repair in any part of the College*”.

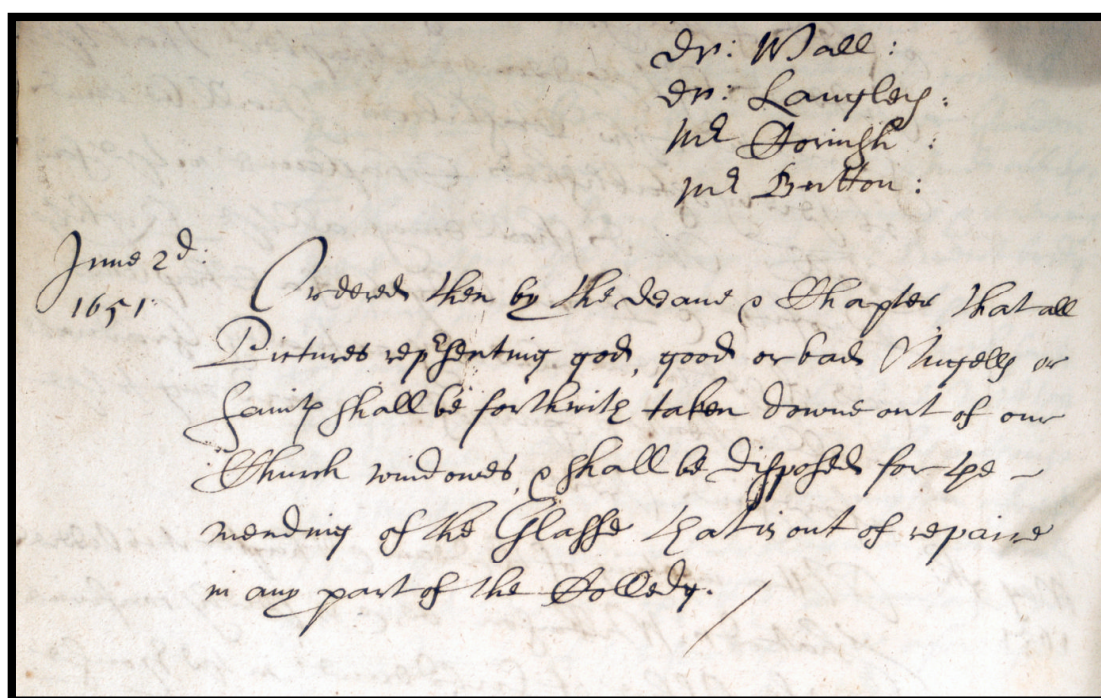


Figure 3-98 Chapter minutes instructing the removal of saintly images dated 1651

This order (Figure 3-98) states that images in glass especially those depicting religious icons should be removed and used to repair windows in other parts of the college. What can be seen in the ‘Jonah’ window is the compliance with this order. The image of Jonah was removed around 1651; image was deliberately damaged during or slightly after the Civil War. It was subsequently replaced by Price c.1696. The window

was then moved around the cathedral and repaired at various points during the Victorian period.

In terms of analysing the glass in order to recreate the windows, some individual panes may pose problems. For example, the pot metal glasses used in Jonah's robes, these glasses may show higher levels of Mn due to the colourant in the glass and this may skew the HH-XRF interpretation. These anomalies would need to be taken into consideration when interpreting the window and attempting to differentiate between the original and the restored areas. Also, because pot metal glass was rare in the 17th century, there is the possibility that these sections were recycled from earlier medieval windows. Alternatively, they could have been created by the Victorians. Therefore, although the HH-XRF works well generally for differentiating the parts of the window, it cannot be relied upon as the sole decider, other more artistic skills would also need to be employed. For example, where the HH-XRF may not be able to differentiate the glass, because it has been recycled, it may be possible for an art-historic interpretation of the image on the glass to define the period in which it was made.

The case study also shows the validity and usefulness of using the HH-XRF for assessing the nature of in-situ glass. This means that the 9000 fragments in the collection can all be assessed quickly and accurately to categorise them into the work of the various artists. This also means that other in-situ windows can be analysed to determine the extent of the restoration work involved. In theory, by using a combination of art-historic analyses, in-situ HH-XRF analyses and other laboratory based analyses, such as SEM-WDS and LA-ICP-MS, it should be possible to determine which glass belonged to which period of history, who painted which windows and how the windows would have looked. In short, it would be possible to recreate the window scheme over time certainly as far back as the grand Van Linge scheme of the 17th century with suggestions as to how the earlier cathedral may also have looked.

3.15 Conclusion

In conclusion, the stained and painted windows within the cathedral of Christ Church, Oxford, have had a varied and in some cases turbulent history. To a certain extent this is reflected in the windows themselves with some obvious areas of restoration. The restorations themselves can also be dated to throughout the cathedral's

history. This has been proven with the HH-XRF work on the 'Jonah' window which has highlighted the areas of the window that have been replaced by different artists over the years. Attitudes towards the windows have changed substantially the cathedral's history, in some cases, for example, with the Price window and the Gerenté window, it is tastes and fashions that have changed. Whereas, in other cases, the images on the windows caused offence, such as is the case with the Van Linge glass. The divided opinion over the nature of the windows is also apparent in the way that certain images were moved around the building. For example, when the 17th century glass went out of fashion, an attempt was made to preserve some of it, by moving its location. The 'Jonah' window is a prime example of this; it was saved at a request from members of the house, but was subsequently put in an unassuming, relatively 'out of the way' location. Out of all the Van Linge windows this one was saved, probably because it was the most complete, and one of the more interesting. 'Christ Disputing with the Doctors' would have been a relatively dull coloured window (the fragments of painted interior scenes found are all grey and the figures thought to have come from this window are beige). 'Sodom and Gomorrah' on the other hand would have been more colourful, but is quite a 'fire and brimstone' subject, whereas 'Jonah' is colourful, contemplative and relatively inoffensive to Victorian sensibilities.

At various times attempts have also been made to reconstruct the windows to varying degrees, for example, when the Gerenté window was removed from the east window it was placed relatively intact into the clerestory lights, since then it has been broken up and made into decorative windows in the tower. The fragments of painted glass now in the clerestory lights are an attempt at preserving some of the decorative pieces without necessarily attempting reconstruction work. The Latin Chapel windows, to a certain extent, show an early attempt at reconstruction, the figures have been placed in the windows with contemporary architectural fragments arranged around them to (re)create the canopies. The restoration of the 14th century glass to the Latin Chapel and the Lucy Chapel show the importance that the Victorians placed on these windows, and the recognition of the importance of the Medieval glass. But, on the other hand, the Victorians neither particularly respected nor cared about the work of the 17th century artists, the 'Jonah' window was lucky to have survived. The 'Bishop King' window is more likely to have survived because of the unique size of the window and the awkward

location i.e. it would have been easier to leave the window in place than try and remove or replace it. Also, the subject was a figural window rather than subject window, which appears to have been the preference for most of the current Victorian windows in the cathedral. In addition to this the size and shape of the other windows in the south Choir aisle have been altered to make this window 'fit in'.

Despite its apparent lack of popularity, the Van Linge window scheme would have been one of the largest and most lavish schemes in the country. The subjects represented and the locations within the building were all carefully chosen to impart a specific message. A number of the windows were 'sponsored' by notable families; and the entire architecture of the windows was altered by Dean Brian Duppa to accommodate the new painted glass. The only surviving description of the scheme is an anonymous poem written in the 1630s, but, even this has been altered over time, the published version being substantially added to. The poem describes most of the windows, but some are only referred to by single words, for example, 'Jonah before Nineveh' is covered by the word *Nineveh*. This has made the reconstruction of the scheme complicated, for example, how many other windows are covered by single words or not mentioned at all, as is the case with 'Christ Disputing with the Drs'? The surviving Van Linge windows in other Oxford college chapels have provided an idea of what some of the art work in Christ Church may have looked like, in some cases, the same theme crops up repeatedly throughout the university. For example, the image of Jonah and the Whale represents learning; hence it is quite prolific in the colleges. There are several different depictions of this theme ranging from individual figures, to type/anti-type panels, to entire pictorial windows. The windows in Christ Church, according to the poem, were all pictorial, and not of the type/anti-type sort as seen at the east end of Wadham and Lincoln college chapels. A second poem comparing the east window of Christ Church with a painted wall in Magdalen College written in 1656, says that the Wadham and Lincoln style of windows are outdated, further implying that Christ Church is mainly scriptural stories.

Due to the size of the cathedral and the number of windows that the Van Linges had to work with, it is feasible that they did not need to fill individual windows with type and anti-type images because they could paint both. The layout of the scheme proposed in this thesis shows how the important messages within the Christian faith

could have been represented in the main windows of the building, with the relevant type and anti-types in close proximity. This method of adorning the building would have meant that worshippers and visitors to the cathedral, whether literate or illiterate, would have had no doubt as to what the messages of the Bible were. Unfortunately, the images were felt to be idolatrous, glorifying the Roman Catholic Church and its traditions along with idolising saints and martyrs. This, along with Christ Church's support of the King, meant that the destruction of these images was as much a political statement as it was of religious intolerance. The prominence of the building and its associations meant that the Puritans had to make an example of the place. Having said this, attempts were made to protect the windows and five are believed to have survived mostly in tact to the Restoration. This thesis is the first study that has been able to reconstruct the Van Linge scheme.

The fragments of glass housed in the Bethel form a large collection of over 9000 pieces. Some of these were sampled and analysed using a variety of techniques. The results meant that glass from different periods could be determined. This combined with an art-historical analysis of the images on the fragments means that not only can the work of specific artists begin to be distinguished, but also, where one artist has restored another artist's work can be seen, such as with Price and the Van Linges. The analyses of the fragments has made it possible to characterise some of the glass compositions being used in the areas at specific times, this in turn allowed a pilot study to be carried out using the handheld XRF. The *in-situ* windows of 'Jonah before Nineveh' and 'Bishop King' were analysed and it was possible to determine not only which panes were replacements but who/when they were done. For example, the work of Price was clearly identifiable from the work of Van Linge based on the composition of the glass. Although the more modern restorations of the window could also be determined, it is not possible at present to say how modern these are. The analyses of the Victorian fragments of glass showed a dispersed group of samples, therefore, more analyses and more work on the Victorian glass is required before conclusions can be drawn as to the nature of the *in-situ* restoration work. What this thesis has shown is that a multi-disciplinary approach, using a combination of art, historical, archaeological and scientific techniques has facilitated the authentication of the standing windows within the cathedral.

Ideally, if more samples of glass from definite periods or artists can be analysed, i.e. more fragments of the Latin Chapel windows or fragments that have definitely been attributed to Oliver, then a database of compositions can be created, and the same could be done for the Victorian artists. A database of this type could be used to characterise the stained glass throughout Oxford, and patterns as to the distribution of glass manufacturers and glasshouses could be created. For example, does all the Van Linge glass in Oxford have the same composition? This study identified a core group and a series of outliers in terms of the Van Linge glass, would the other chapel windows conform to this pattern or will more distinct Van Linge groups emerge? Is all the Price glass in Oxford of the same compositional group, suggesting that Price acquired his glass from a single source? A more detailed study of the lesser known artists, such as Oliver, would allow a comparison to be made as to the changing glass composition throughout a relatively short period of time. The further development of such a database may show that individual Van Linge windows are identifiable based on glass composition and that this current study just didn't have enough samples or happened to have the few anomalous samples, i.e. the outliers to the core group.

The promising work with the handheld XRF means that *in-situ* windows can be analysed without damaging the window, and this will allow the identification of genuine work from replica work. For example, although the restoration work of Price looks out of place in 'Jonah before Nineveh' it is in itself a valuable work; it represents a 17th century restoration of earlier art. This analysis means that any future conservation work on the windows can be carried out in sympathy with the existing work. Further work on the use of the XRF for *in-situ* window analyses combined with a database of Oxford compositions would mean that if, as is suspected to be the case with 'Jonah before Nineveh', certain fragments from other similar Van Linge windows were used to complete one fragmentary window, then they could potentially be identified, possibly even to the extent of which window they originally came from.

The images and stained glass windows in Christ Church Cathedral tell a story; on the surface they represent biblical passages saintly figures, or the lives of iconic people. But, beneath this surface the windows tell the story of their own turbulent history. The analysis of the fragments in the collection has allowed the study of the 'Jonah' window, and this in turn has revealed the history not only of the window but of

the entire Van Linge scheme. If this approach were applied to all the windows within Christ Church, then maybe a complete picture and subsequent reconstruction of the different artistic and architectural phases could be created, for example, a virtual tour of Christ Church through the ages.

“The concept of the timeless value of a work of art, and its ability to be understood even when isolated from its context...is, indeed, a modern idea” (Raguin 1990: 317).

4 Study 2: Automotive Glass

Trace evidence is the key to understanding a crime scene; this is based on Locard's Principle, where every contact leaves a trace (Carrier & Spafford 2003). Trace evidence is minute fragments of material that are left behind after contacts. This could be, for example, fibres, glass, paint or soil (Kaye 1995). Every crime will have some form of trace evidence left behind, but the exact nature of this varies depending on the crime committed. In crimes where glass is a form of evidence it is usually very prolific, for example, if a window has been broken to gain entry to a property. Glass, however, is not necessarily present at every crime scene, and in the majority of crimes glass is not part of the available trace evidence.

Automotive glass is one of the most common forms of evidence (Zadora 2009) when it is found present at a crime scene; this is one of the reasons why this type of glass was chosen as a case study for this thesis. Another reason was because of the relative ease of obtaining datable samples of auto glass compared to other types of window glass, such as architectural glass. Most car windows have a stamp on one of the lower corners, this contains information relating to the glass manufacturer, the plant at which the glass was made, and the date the glass was made. This case study focuses on using forensic and archaeological analytical techniques and applying them to modern glass, in order to attempt to provenance the auto samples. This case study begins by examining the different classifications given to modern glass, and the different types of glass within those categories. The chapter then looks at the manufacturing techniques used to create these glasses and a brief production history of each method. The composition of modern glass along with a discussion of the raw materials involved in making modern glass follows, before a discussion on the specifics of forensic glass analysis.

In order to understand the proliferation of glass at a crime scene and how the fragments may be transferred to a suspect, it is necessary to understand how and why glass fails. Although this case study does cover the manufacture and use of modern glass, the focus is on automotive glass, so a description of how car windows are made along with information relating to who manufactures automotive glass. In order to understand the complex relationship between car manufacturers and glass

manufacturers, a survey of car windows was made. The information relating to which car manufacturer is employing which glass manufacturer at a given time is commercially sensitive, this means that it can be extremely hard to obtain. A survey of car windows across the Defence Academy (DA) was catalogued the windows within 300 cars. This survey enabled a study not only of who was providing glass to whom in a given year, but also indicated how many cars had window replacements. Although this method was able to give an indication of which windows were most likely to be replaced, it was not able to show how frequently this occurred. For example, if a 2002 car had its windscreen replaced in 2003 and then again in 2007, only the 2007 replacement would be apparent in terms of the survey.

The information gained from the survey was used to determine any patterns relating to the manufacture of car windows. Samples of auto glass were collected from scrap yards and any available information relating to the vehicle and the window was recorded. These 24 samples were then analysed using forensic and archaeological techniques in order to determine the chemical composition, and optical properties of the glass. These analyses were then used in an attempt to determine the provenance of the samples. The limitations of the study are also discussed, and finally, conclusions are drawn as to the usage of different analytical techniques to differentiate and provenance auto glass.

4.1 Classification of Modern Glass

Most modern glass can be classified into simple groups, these are often arbitrary (Hickman 1981), and are used to help determine what type of glass is being discussed, and whether it has originated from different sources or not (Harrison et al. 1985). This is especially important in terms of the forensic analysis of glass. The traditional divisions of glass groups are window, vehicle, container and tableware (Hickman 1981). The latter two groups are extremely diverse and can include items such as drinking glasses, lead crystal glasses, dishes, ashtrays, vases and candle holders (Hickman 1981). Different types of glasses have different manufacturing processes and these processes can alter the physical and chemical properties of the glass (Trejos & Almirall 2005). The categories relate to the general usage to which the item is put, and in many cases will involve some overlap, for example, container glass and tableware.

4.1.1 Container Glass and Tableware

The categories of container glass and tableware are perhaps more arbitrary than the other glass categories, because they involve the most overlap. Many items can be placed in either group, and some of the manufacturing processes are very similar. For example, many common drinking glasses, such as pint glasses, could fall into either category. More decorative items are likely to be classed as tableware, but again, this would mostly depend on who was doing the classifying or where the classification was taking place. Because of the high level of overlap between the groups and the manufacturing techniques, container glass and tableware will be discussed together.

Since the 17th century, there was intense competition amongst European glassmakers to create a thick, robust and colourless glass which could withstand the deep engraving techniques common for the period (Vose 1980). This was partly because of the fashion for engraved glassware, and partly due to the rising division in opinion of how glass should be treated, i.e. as a plastic, to be molded, or as a crystal, to be cut and polished (Klein & Lloyd 1991). During the 18th century there were steady improvements in the glassmaking techniques, which paved the way for the 19th century to become ‘the golden age of glassmaking’ (Vose 1980). *“At no time since the Italian Renaissance had there been such an explosion in new glassmaking methods and ideas, and all over Europe there was keen rivalry in inventing new types of art glass for a highly competitive market. The day of the glass technologist had dawned, with large firms hiring scientists specifically to discover new methods of making and decorating glass”* (Vose 1980: 81). The new technologies and designs meant that glass products were affordable to a much wider range of customers. Although the methods, tools and processes of glass manufacture changed relatively little in the 19th century, even with the introduction of mechanisation, it was the attitudes towards glassmaking which changed. Glass manufacture went from being *“a slightly haphazard affair with a faint air of mystery still attached to it...[to]...much more scientifically based as the century progressed”* (Klein & Lloyd 1991: 169).

The leading glass houses began to employ chemists, and furnace technology improved, giving glassmakers a new confidence to experiment with designs and colour (Klein & Lloyd 1991). The development of press-moulding in America in c.1830 made

glass available to the poorest households (Vose 1980). Pressing required suitable moulds and muscle power, but it could only be used for a limited range of shapes (Cable 1999). The pressing mechanism consisted of a table fitted with interchangeable metal moulds, and a plunger which thrust into the mould from above. This technique produced ready decorated tableware, often with imitation cutting, but without the need for blowing or manipulation of any kind (Vose 1980). In the early part of the 20th century pressing was widely exploited to make low quality tableware. There were two major advances in terms of pressing, these were to operate the machine pneumatically and to use put several moulds on a rotating table, thereby increasing the production rate and decreasing the labour costs (Cable 1999). The quality and range of pressed wares did improve and by the 1940s items such as Pyrex were familiar (Cable 1999).

Although the shapes achieved by pressing can be extremely accurate, the surface quality is often poor, resulting in the need for close control at the glass-mould interface. A common defect caused by poor control was a series of parallel or concentric waves called ‘washboard’. A lot of the early pressed ware was patterned specifically to hide this defect (Cable 1999).

The next real developments to the container glass industry occurred during the 1880s. An Englishman, William Ashley, invented a semi-automatic bottle-making machine (Vose 1980). The mechanisation of bottle and jar manufacture required several things, a) to begin by making the mouth or ‘finish’ of the container, b) to use a suitable parison (blank) mould, c) to use pneumatic or electric power to drive the machine and to provide compressed air and a vacuum, d) to have an efficient mechanical method for supplying gobs of glass to the machine, e) to use metal moulds (Cable 1999). Ashley revised his machine several times, and at one point he had 10 machines in operation and two workers producing c.2150 bottles per day per machine (Cable 1999). The disadvantage of the machines was the need for a skilled worker to gather the glass and fill the parison mould. The first fully automatic bottle-making machine was built in Toledo, Ohio, by an American, Michael Owens, in 1903 (Vose 1980).

In terms of automatic bottle/jar making machines there are a variety of methods which can be used. The common methods are the ‘blow-and-blow’ process for narrow necked containers and the ‘press-and-blow’ process for wide mouth containers (Varshneya 2006). Although there have been many developments in the individual

aspects of the mechanisation, the principal methods are outlined below. The most popular 'blow-and-blow' automatic machine is the Hartford I.S. (Individual Section) machine. The machine consists of 5-12 separate mini-machines operating in sequence. The gob of molten glass is dropped into the parison and fills the cavity below making the neck of the container. Air is blown into the glass forming the parison shape. The parison mould opens and the arm holding the neck of the container swings it into the finishing side, where the finishing mould closes around the parison. Air is again blown into it to make the glass into the final shape. The mould opens and the container is cooled before being conveyed to the annealer (Varshneya 2006). In the press-and-blow process the gob is dropped into the parison and a needle-plunger pushes into the glass to force it into shape and make the parison. The molds open and the parison is dropped into place ready to be blown into the final shape (Varshneya 2006). The containers are also often coated either at the entrance to the annealing lehr (hot-end coatings) or at the exit (cold-end coatings). These are usually designed to protect the glass from abrasion either during the manufacturing process or from rubbing against each other (Varshneya 2006).

4.1.2 Vehicle Glass

Vehicles have a number of glass components which can all fall into the category of vehicle glass, these include the car windows themselves, which are often coated and either toughened or laminated; but also the front and rear lights of the vehicle. In terms of the vehicle lights, the bulbs are still made of glass, and sometimes the case surrounding the light is made of glass although today is more likely to be plastic. Vehicle windows are made from flat glass, usually by the float process, but in the case of some older vehicles, the windows may have been made from plate glass (the processes for manufacturing these types of glass are outlined below). When vehicle glass is encountered in forensic cases it is usually from the windows of the vehicle, headlight and mirror glass can occur but is less common (Lambert & Evett 1984).

4.1.3 Window Glass

Window glass is generally defined as any glass that is used as a window in a building. *“No feature in domestic architecture requires more consideration than the window. To give the requisite amount of light, without unduly cutting up the wall; to admit air when you want it, without admitting wind and wet, which you do not want; to have free scope for viewing external objects, without needlessly exposing your rooms from the exterior; and to do all this in such a way as will add beauty and character to your building, both within and without, are important objects to be aimed at in any style”* (Scott 1858: 24). This sentiment is still true of windows and the design and manufacture of them is something that takes a lot of consideration and care. The development of the window demonstrates the demands that have been necessitated by industry, commerce, agriculture, politics, culture and religion over time (Louw 2007).

Although windows and window glass have existed since the Roman times (Louw 2007), it was only with the development of the sash window in the Georgian period (1714-1830) that it became possible to achieve all the properties that are now a pre-requisite of a functioning window (light, air and views) (Louw 2007). In Britain it was during the 16th century when the potential for the use of glass in secular windows was realised, although churches had been using glass since the Saxon period (Vose 1980). During the reign of Elizabeth I the use of the window in secular architecture increased, this is mainly because of the development of the flat glass industries (Louw 2007), which allowed more ‘flat’ glass to be rapidly produced. This is where large panes of ‘flat’ glass are produced, which can then be used for the manufacture of windows, mirrors, and other flat objects.

Over the years, the architectural style of the window has changed i.e. the shape of the overall window and its relationship to the building in which it is located. The size of the individual lights within the window changed depending on the fashions of the time, along with the type, and manufacturing techniques for flat glass that were available. Some Victorian architects had progressive views on the use and development of windows, but in general Britain was slow to adopt the views of the Modern Movement, who reduced the window to *“a standard device designed to admit a measurable quantity of air and light”* (Louw 2007: 47). The materials used to create the window and the window spaces changed, for example, steel and concrete were used to

create the frames. The idea of the window being a ‘hole-in-the-wall’ was replaced by new ideas of transparency, functional utility and structural integration (Louw 2007). Today, there are a wide variety of window designs that can be seen. These range from small domestic windows designed to allow light and air to a property, often designed to ‘fit’ with the contemporary architecture of the building, to large scale window ‘walls’, where the wall of the building is purely made from glass.

4.2 Composition of modern glass

The majority of all modern glass produced is flat glass, used for windows, mirrors and automotive applications, container glass or glass used for lamps. These glasses all have very similar compositions and are soda-lime-silica glasses (Shelby 2005). Most of the glass therefore encountered in forensics is of a basic soda-lime-silica composition; although, occasionally, contamination of the melt can occur along with deliberate additions of oxides such as boron to influence the physical properties of the glass. A number of other glass compositions for specialist applications are known (Shelby 2005) and these are occasionally encountered during forensic work. The ‘typical’ compositions of commercial soda-lime-silica glass are outlined in Table 4-1.

Component (wt%)	SiO₂	Na₂O	K₂O	MgO	CaO	Al₂O₃	Fe₂O₃	SO₂
Windows	73	14	-	4	9	0.1	0.1	-
Containers	74	13	0.3	0.2	11	1.5	0.04	0.2
Lamps	72	16	1	4	3	2	-	-

Table 4-1 Common Commercial Glass Compositions (Shelby 2005: 265).

The ‘standard’ composition of modern glass often quoted as 63-74% SiO₂, 12-16% Na₂O, 7-14% CaO and cullet (Curran et al. 2000). Any contamination in the melt is usually present in the form of trace elements in the glass, these can be caused (as mentioned above) by the manufacturing process itself, or they can occur ‘naturally’ as inclusions with the raw materials. These contaminants can cause undesirable effects in the glass, such as colour. In this case, manufacturers will use a range of oxides to ‘decolourise’ the glass, these include CeO₂, SbO, NaNO₃, BaNO₃, K₂SO₄, BaSO₄ and in the past As₂O₃ (Curran et al 2000). Also, most commercial glasses will contain small amount of fining agents (used to remove the bubbles from the melt) these include,

As₂O₅, Sb₂O₅, KNO₃, NaNO₃, NaCl, CaF₂, NaF, Na₃AlF₆ and some sulphates (Shelby 2005). If a specialist application of the glass is required, other oxides are deliberately added to give the glass the specific properties needed such as boron oxide for improved heat durability. These additions and impurities can be used to discriminate glass of the same type (Curran et al 2000).

As mentioned earlier, some applications require the glass to have specific properties, and although these are not necessarily a common occurrence in forensic analyses, they do sometimes occur and therefore, a brief mention of their composition and properties will be made here. The most likely ‘specialist’ glasses to be encountered are borosilicate glasses (Table 4-2). These glasses occur in a wide range of compositions, mostly depending on the application for which they are intended. Borosilicate glasses are generally chosen for their better thermal shock resistance, better chemical durability, and higher electrical resistivity than soda-lime-silica glass (Shelby 2005). There are a large number of other common commercial glasses for various applications, and their compositions can be based on silica, Germania, boric oxide, phosphoric oxide, heavy metal and other fluorides (Shelby 2005). But, they are not likely to be routinely dealt with in a forensic or archaeological context and are therefore beyond the scope of this thesis.

Component (wt%)	SiO₂	B₂O₃	Na₂O	Al₂O₃
Pyrex	81	13	4	2

Table 4-2 ‘Typical’ composition of common borosilicate (Shelby 2005: 267).

In recent years the glass industry has improved the quality control of the manufacturing process through the use of a computerised delivery of raw materials and the standardisation of methods and formulations throughout the world (Koons & Buscaglia 2001). Although the methods and formulae may be standardised, i.e. the amounts of raw material used and the way in which the batch is melted, individual glass manufacturers will still use different sources of raw material and it is this which will impart a signature to the glass.

4.2.1 Raw materials used in production of window glass

Modern glasses are either produced from high quality, chemically pure components, or from a mixture of less pure minerals (Shelby 2005). Typically, research specimens, optical glasses, and glasses used for high technology applications tend to be produced from the pure chemicals whereas, bulk commercial products are produced from minerals (Shelby 2005). Minerals can often contribute several different components to the melt, for example, anorthite feldspar will contribute lime, alumina, and silica to the batch. Minerals are often chosen based on the yield of particular elements that they give. Glass manufacturers need to be aware of what components may be added with which minerals in order to modify the recipe and still produce a workable glass. Most introductory texts on glass science and technology will give tables of data indicating which minerals contribute which components to the melt (Tooley 1984b; Varshneya 2006; Shelby 2005).

In terms of the silica source used for modern glass, the sand chosen has to be of a very specific quality. For example, clean quartz sands with high quantities of shell and salts would be rejected by the glass industry as the effort and time needed to alter the glass recipe to take account of these additives would be too much (Akpokodje & Etu-Efeotor 1987). The size of the sand grains is another important factor, the grains need to be small enough to provide a large surface area and make them suitable for melting, larger grains can often be caught through sieving and then crushed to the required size, but grains that are too small are not accepted. The most important impurity in sand deposits is iron oxide, this is deemed as within acceptable limits for glass manufacture if it constitutes <0.5% of the deposit (Akpokodje & Etu-Efeotor 1987). Sands that have a higher percentage than this are often discarded as the beneficiation processes for removing the iron are too complex and costly (Akpokodje & Etu-Efeotor 1987). According to the Pilkington website only high quality ingredients are used including sand, soda ash, limestone, saltcake and dolomite. The soda ash is used as a flux to lower the melting temperature, the limestone is added as a stabilizer to improve the durability of the glass, and the dolomite is added to improve the working and anti-weathering properties. These ingredients are generally used in the following proportions (Table 4-3):

Sand	Soda Ash	Limestone	Dolomite	Alumina	Others
72.6	13.0	8.4	4.0	1.0	1.0

Table 4-3 %s of raw materials in Pilkington float glass taken from the website June 2010

As has been mentioned above, it is usually the highest quality raw materials that are chosen to make glass, especially if the colour (or lack thereof) is an important feature. The nature of the raw materials can also affect the production process as well as the final product, and the cost of creating the glass is not always minimised by using cheaper raw materials (Cable 1984). Something else glass manufacturers have to consider when choosing the raw materials, is the environmental impact (Cable 1984). For example, the choice of raw materials will have differing volatilisation corrosion effects within the furnace, and in some cases can lead to serious atmospheric pollutants being released. There is a lot of consideration surrounding the complex chemical and physical processes involved with melting different raw materials which must be considered along with the other environmental and cost issues when making a choice. *“No simple rules allow the best choice to be made without trial and error experimentation. This is one important reason why glass-makers rightly tend to be very conservative about making changes in their operations”* (Cable 1984: 5).

4.3 Glass Production Techniques

“The study of the imperfections in an old piece of window glass can give clues about how it was made, and that in turn may offer guidance about its provenance” (Martlew 2007: 123). Panes of older window glass may have been made using one of the techniques outlined in section 1.4.2.4. For example, crown glass and cylinder glass were common methods for producing panes of flat glass. But, in terms of more modern glass, the development of mechanised flat glass manufacturing techniques allowed the production of large sheets of glass. Victorian glassmakers were under pressure to increase the production of window glass, partly because of the removal of the window tax in 1851 and partly because of the removal of the excise duty on glassmaking in 1845 had increased the demand for windows (Martlew 2007). The glass tax in Britain had weighed more heavily on the flat glass industry than it had on decorative glass or tableware; in some cases it had added as much as 300% to the basic production costs (Klein & Lloyd 1991). This along with the pressure to reduce costs due to competition

with Belgium and other European countries meant that the 1860s was a period of major innovation in terms of glass production (Martlew 2007). The first changes which allowed the mass production of glass were in furnace design, and these were closely followed by attempts to make glassmaking a continuous process (Martlew 2007). Until this point a glass melt had been made in a crucible and the glassworker had then blown, spun and cut the glass into the required shape.

A series of complex experiments were carried out by the Siemens brothers with pots which allowed the continuous acceptance of raw material at one end and allowing the molten glass to be gathered at the other. This process failed because of the corrosive nature of the melt (Martlew 2007). The brothers realised that the answer was to contain the glass in one large tank rather than in pots. In 1869 the brothers built their first tank furnace in Dresden, and by 1873 continuous tank furnaces were in use in St Helens for the manufacture of window glass (Martlew 2007). These 'regenerative tank furnaces', as they were known, were used not only to make flat glass items such as windows and bottles, but also cheap, mass produced tableware (Vose 1980). The regenerative furnace has remained in use to the present day with only minor changes (Vose 1980), and it is these changes which determine the production method of the flat glass. In terms of modern flat glass (which is the way in which most window glass is manufactured), the three main types are sheet glass, plate glass, and float glass. These flat glasses are all soda-lime-silica in composition, but the methods of manufacture differ, as is outlined below.

4.3.1 Sheet Glass

The earliest methods of producing sheets of glass were based on the cylinder method. The basic principles of this method are outlined in section 1.4.2.4. During the late 1800s attempts were made to mechanise and therefore modernise the production of cylinder glass. The first successful commercial process for making drawn cylinder glass was patented by the American J.H. Lubbers (Martlew 2007). In his process, molten glass from a melting furnace was poured into a specially designed crucible. A hot metal 'bait' was lowered and dipped into the molten glass. The bait would then be withdrawn slowly, drawing a cylinder of glass after it. Pressurised air was introduced to the cylinder to prevent collapse and to dictate the diameter of the glass. By regulating the

drawing speed, air pressure and temperature operators could produce a desired wall thickness and maintain that until all the molten glass had been used up (Martlew 2007). Cranes would then lower the cylinder onto a horizontal cradle where the glass would be split, flattened and annealed. The flattened ‘shawl’ (length of flattened cylinder glass) would be around 3.8m by 1.5m, and often proved difficult to handle due to the large size, and this in turn would introduce further surface defects to the glass (Martlew 2007). The Lubbers process continued in use until around 1930, but the resulting glass was often seen as cheap and inferior to some of the more traditional hand-blown glass on the market. Also, due to the nature of some of the defects, large panes of glass of any real quality were hard to obtain with this method and the more expensive polished plate glass was often chosen instead (Martlew 2007).

4.3.1.1 Fourcault Process

The first method of mechanical ribbon drawn flat glass production was developed during the early 20th century. This was the Fourcault updraw process developed in Belgium. In this process, the components of the glass are melted in a large tank, and the glass enters the Fourcault canal, a 3m long clay block called a ‘debiteuse’ with a slot in the centre is floated on the glass (Varshneya 2006). The slot ran the length of the debiteuse, and allowed molten glass to well up inside (Martlew 2007). The molten glass is picked up on a ‘bait’ and is then pulled through the slotted refractory through a system of cast iron or steel rollers to about 7m in height (Figure 4-1) (Varshneya 2006). Water-cooled pipes near the slot were used to cool the newly-formed sheet, to increase its viscosity and to stabilise the ribbon against collapse, and the rollers were positioned every 500mm up the tower (Martlew 2007).

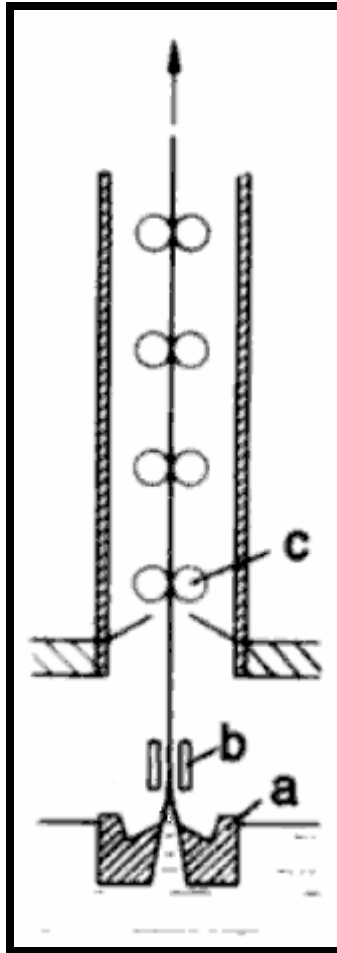


Figure 4-1 Picture of Fourcault Process, a) the debiteuse, b) the coolers, c) drawing rollers (Pfaender 1996: 58)

The thickness of the glass is determined by the glass viscosity and the drawing rate; thicker sheets are produced by slower drawing rates (Varshneya 2006). The lengths of the panes of glass were only limited by the handling considerations (Martlew 2007). The glass made in this way then had to be fire finished or polished (Curran et al 2000). Little by little the tank itself dissolves into the molten glass, and therefore there were also traces of the tank present in the final glass product (Curran et al 2000).

When it was first introduced, the Fourcault process was not able to match the quality of the hand-blown cylinder glass process, but it gradually became the process of choice and remained so in terms of sheet glass until the middle of the 20th century (Martlew 2007). The ribbons of glass often had a noticeable waviness to them and due to the minor variations in thickness, often had minor visual distortions to the glass (Curran et al 2000). These variations and waviness were caused by gravitational forces acting on the vertically suspended glass ribbons. Also, because of the corrosive nature

of the glass melt the slot edges of the debiteuse became worn and irregular often causing an irregular thickness to the glass sheets (Martlew 2007). As mentioned before, the refractory material often ended up in the final glass and the process of drawing the glass vertically meant that these impurities caused streaks known as ‘music lines’ on the glass surface. This is often seen as the ‘fingerprint’ of the Fourcault process (Martlew 2007). Other defects commonly found in this type of glass were bubbles. High levels of sodium sulphate in the raw material caused larger sulphur bubbles (‘bleib’) to form, which then encouraged the formation of crystalline sodium sulphate deposits. Reducing the amount of sodium sulphate used reduced the amount of large bubbles, but caused the amount of small or ‘seed’ bubbles to increase (Martlew 2007). These defects also meant that undigested sand grains (‘stones’) could find their way into the melt causing further distortion to the glass (Martlew 2007).

4.3.1.2 Libby-Owens-Ford – Colburn Process

In 1898, the American Irving W. Colburn began working on a flat-drawn window glass process (Martlew 2007). The Libby-Owens-Ford – Colburn process also involved the drawing of a continuous ribbon of glass from the melt, the difference being that the ribbon was subsequently bent around a roller and into a horizontal position (Shelby 2005). Colburn employed a horizontal refractory slab to stabilise the foot of the drawn ribbon. This was known as the ‘draw bar’ and was mounted around 50mm below the glass surface completely immersed in the molten glass (Martlew 2007). Colburn mounted a polished steel roller about a metre above the glass surface and it was around this that the ribbon was bent horizontal (Martlew 2007). This meant that rather than needing a large tower in which to draw, anneal and collect the glass, and subsequently lower to the ground, the whole process could happen at ground level in a horizontal ‘factory’ style. The process could happen at twice the speed of the Fourcault process and the ribbons of glass could be much wider (Martlew 2007). The thickness of the glass was determined in the same way as for the Fourcault process.

4.3.1.3 Pittsburgh Plate Glass (PPG) Process

The PPG process for sheet glass manufacture was developed by Harry Slingluff on behalf of the Pittsburgh Plate Glass Company. In 1926 Slingluff patented a process which was a combination of both the Fourcault and the Colburn processes. His method used the vertical draw tower of Fourcault along with the draw bar of Colburn. Although not as fast as the Colburn method, it did reduce some of the imperfections that both of the previous techniques suffered from; in the early 1930s it was introduced to the UK and subsequently displaced the Lubbers process to become the dominant method for sheet glass production (Martlew 2007).

4.3.2 Plate Glass

Plate glass was developed to overcome the problems of visual distortion that were occurring within the sheet glass. Plate glass is where a blank of glass is created by pouring the melt onto a flat base and it is then rolled (Curran et al 2000). The plates of glass are then ground and polished on both sides. This type of glass had better quality optical properties, but lacked the strength of other types of glass due to the surface imperfections generated by the grinding and polishing (Varshneya 2006).

Plate glass was originally formed by casting molten glass onto a metal table and rolling it into a sheet. In a similar way to sheet glass, the surface of the glass reproduced the flaws from the rollers and table surfaces. Therefore, the glass was ground and polished to a parallel, high quality optical finish (Shelby 2005). This process involved sacrificing the thickness of the glass in favour of quality, this was a costly and wasteful option (Martlew 2007). Grinding was achieved with the use of sharp silica sand suspended in water, and successively finer grades were used as the process progressed. The final stages used finely divided red iron oxide applied as a slurry, known as 'jeweller's rouge' (Martlew 2007). This resulted in a flat, but not necessarily 'unscarred' or optically perfect glass.

The earliest plate glass was Roman in origin and was cast on a flat slab of stone covered in sand and teased into shape with tools. Both surfaces of the glass were matt and had very visible irregularities. No attempts were made to grind or polish this early glass (Martlew 2007).

4.3.2.1 The British Plate Glass Company

The British Cast Plate Glass Company was established in St. Helens in 1773, by an ex St. Gobain worker, Philip Besnard who was charged with the task of bringing plate glass manufacturing techniques to England (Martlew 2007). James Watt provided the steam engine and designed the grinding and polishing systems which allowed the company to mechanise the process and thereby avoid breaking the glass (Martlew 2007). The plate glass technique continued in Britain relatively unchanged through the 19th century (Klein & Lloyd 1991).

4.3.2.2 The Bicheroux Process

The Bicheroux process was developed by the German engineer Max Bicheroux. It had long been observed that casting the glass onto a table produced a rippled surface because of the way the molten glass contracted when its lower surface came into contact with the chilled surface of the iron. In order to reduce the costs and wastage created by having to produce extra thick glass to compensate, of which half was ground away, Bicheroux reasoned that shallower ripples would be created with less contact from the metal. Bicheroux's process involved casting the glass into a pair of rotating rollers so that a sheet could be formed using minimum contact time with the metal; the glass sheet then slid down an inclined plate to be cut into manageable lengths (Martlew 2007).

4.3.2.3 1920s Onwards

In the 1920s, a partnership was set up between Ford (who wanted plate glass for their car windscreens) and Pilkington Brothers (renowned for producing high quality glass from continuous tank furnaces). The Ford engineer C.W. Avery also passed the glass through rollers, but he used hollow steel rollers through which he passed water to keep them cool. This continuous ribbon of glass passing along a conveyor allowed continuous annealing and grinding of the top surface (Martlew 2007). The process continued to be developed until the 1930s, by which time, continuous grinding of both surfaces was possible, but continuous polishing could only occur on one surface and the

other had to be dealt with offline after the plates were cut into manageable lengths (Martlew 2007). The whole process was much more economical but there were still high costs involved with the factory set-up, and high energy consumption costs (Martlew 2007), but despite this, plate glass remained the most superior glazing product until the 1950s.

During the 1950s the flat glass industry grew rapidly, and one such company to experience this rapid growth was Pilkington. In c.1949 Pilkington identified the need to radically improve or replace the grinding and polishing process involved in making plate glass (Bricknell 2007). This led to Pilkington experimenting to develop a new method of producing flat glass, the float process.

4.3.3 Float Glass

From the late 1930s Pilkington was seeking ways of improving the costly and time-consuming grinding and polishing associated with the manufacture of plate glass, and the idea of floating the glass on a bed of molten metal was not new (Cable 1999). The earliest patents for aspects of the float process date back to 1848, when Henry Bessemer suggested supporting the glass on molten metal, but he lacked the resources or technical knowledge to achieve this (Cable 1999). The ideas for floating the glass on metal continued to be suggested for various reasons but no-one could develop a process for actually achieving this. In the 1920s PPG made an unsuccessful attempt to float glass on molten antimony, but the outbreak of WWII caused further work on the idea to be deferred (Cable 1999).

The post war rebuilding in domestic and commercial glass markets, and the sharp rise in the automotive industry, along with an increased demand from overseas markets gave Pilkington the financial strength it needed to fund research into the float process during the 1950s (Bricknell 2007). A Pilkington engineer, Kenneth Bickerstaff, was experimenting with molten tin to support a ribbon of glass at c. 600°C. It was not until Alastair Pilkington suggested that the process may work better if the glass were floated on tin at c. 1000°C and then cooled to 600°C as the glass travelled along the bath (Cable 1999). Sir Alastair's method meant that the ribbon of glass could be fire finished on both sides with no need for further grinding or polishing (Bricknell 2007). Small-scale pilot plants were built between 1952 and 1955 (Cable 1999). The problem with

this original process was that only glass of one thickness could be made (Cable 1999), and there were imperfections in the glass caused by the tin/glass interface (Bricknell 2007). By 1955 it was reported to the Board that *“It appears probable that this process will produce plate glass quality at sheet glass prices. If these hopes are realised its possibilities are unlimited and it is capable of replacing all the existing processes for making transparent glass”* (Bricknell 2007: 60). It was during 1955 that the first full-sized float glass plant was built at Cowley Hill, St Helens, and began operation in May 1957, but it was July 1958 before any saleable glass was produced (Cable 1999). It took 5 years of development and over £5 million in capital and running costs before the plant produced an acceptable yield in 1959 (Bricknell 2007).

The limited thickness of the glass produced was acceptable for most purposes (6.4mm), but there was a growing demand for thinner glass of 3.2mm for the automotive industry. This size was difficult to make via the plate process, but it appeared unlikely that it could be made by the float process either. It was 1962 before Pilkington could announce the production of thin float glass (Bricknell 2007). The surface of the float glass also had a tendency to ‘bloom’ when subjected to toughening processes, but this too was overcome by the mid-1960s (Bricknell 2007).

The first trials of the toughening of the glass occurred at Triplex, a major UK customer who produced the toughened glass for all of the British automotive industry (Bricknell 2007). Toughened glass is commonly used as safety glass; this is where the pane of glass has been heat treated to strengthen it, and on breaking, the glass shatters into small cubes rather than sharp shards (Curran et al 2000).

The Ford Motor Company was experiencing difficulties in obtaining large quantities of plate glass needed for car windscreens, and so after WWI the company decided to make its own plate glass (Cable 1999). It was during this period that the company first partnered with Pilkington, and it was also Ford who became the first manufacturer to convert entirely to the float process (Cable 1999).

In the modern float process the glass is floated on a bath of molten tin (Figure 4-2) (Varshneya 2006). The use of liquid tin leads to a smooth and flat surface on both sides of the glass, the glass is then pulled across the tin surface by metal rollers (Curran et al 2000). The thickness of the glass is controlled by the surface tension, the equilibrium value being 7.1mm; other thicknesses of glass are produced by either

stretching or compressing the cooling melt (Shelby 2005). Since the 1960s the flat glass industry has converted almost entirely to the float process, and as a result most recent forensic glass collections will contain a higher percentage of float glass than older collections (Koons & Buscaglia 2001). *“The superior quality of the float glass combined with the high efficiency and the economics of the process have virtually rendered all other flat glass making processes obsolete”* (Varshneya 2006: 618). As a result of floating on molten tin, some of the tin penetrates into the glass surface, and this surface will fluoresce (Varshneya 2006). The float surface of the glass is therefore tin enriched, while the opposite surface of the glass is depleted in various elements leaving it silica enriched (Curran 2003), and if the glass surfaces are analysed these enrichments can often be detected.

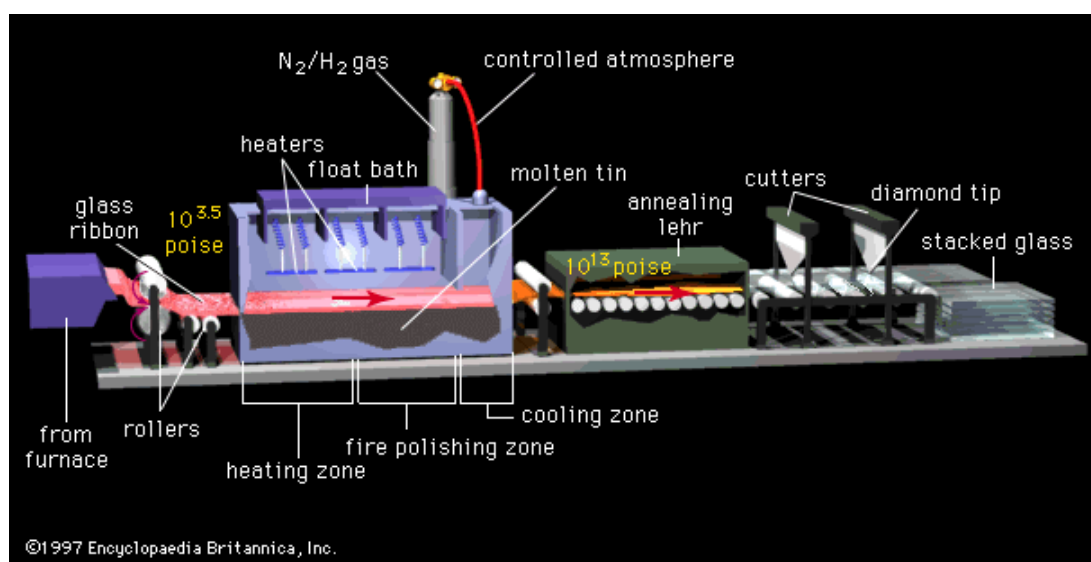


Figure 4-2 Picture of the Float Process (Encyclopaedia Britannica 1997)

A problem which has hit the float glass industry in recent years has again been a technical challenge. NiS nodules have been forming in the glass, Ni and S have been reacting in the furnace chamber and ‘raining’ onto the glass. The liquid NiS droplets crystallize at lower temps to form nodules, and it is these nodules that have been associated with the failure and fracture of the glass in high winds and in high-rise buildings (Varshneya 2006).

4.4 Forensic Glass Analysis

In terms of the analysis of glass, forensic scientists employ a variety of techniques. The first step in any glass analysis and comparison is to inspect the fragments visually and determine whether there is a fracture match between any of the recovered fragments and the source fragments; this is rarely found in real cases (Trejos & Almirall 2004). If the fragments found on a suspect are large enough then they may be able to be ‘fitted together’ to form a physical fit with the control glass thereby indicating they are from the same source. In the same way, if the fragments are large enough they may display a tell tale surface curvature (Howden 1981). This method is only really of use if the fragments of glass encountered are large; in many forensic cases, especially if the glass is recovered from the clothing of an individual it can be extremely small in size. *“When choosing an analytical method for glass analysis for forensic purposes, one should take into account that the amount of material is usually very small, and the material has to be processed to avoid the destruction of evidence. So the method chosen should be non-destructive”* (Zadora 2007: 174).

4.4.1 Refractive Index (RI)

Refractive Index (RI) provides a high degree of discrimination between known and questioned glass samples (Curran et al 2000). Although RI is a useful technique for the examination of glass fragments, due to a narrowing of the variation of RI among glass samples, the discrimination power of RI alone is sometimes not enough to generate conclusive associations (Trejos & Almirall 2005). In terms of forensic glass analysis, RI measurements are usually made in sodium light at 589nm. At this wavelength, the most common RIs for different glass types are highlighted in Figure 4-3 and Figure 4-4 (Foster & Freeman).

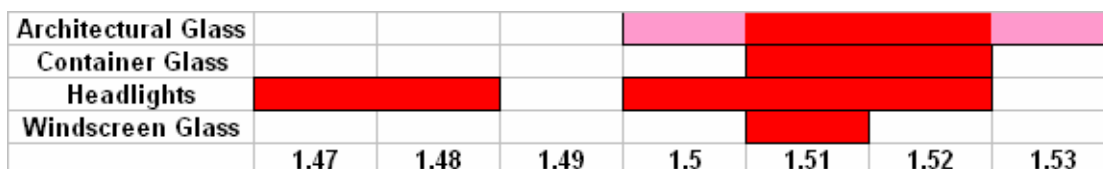


Figure 4-3 Chart showing the overlap of glass RIs

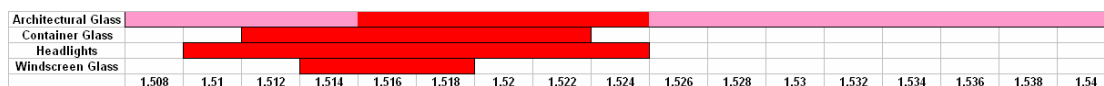


Figure 4-4 Expansion of above chart

As can be seen from this, there is quite a lot of overlap between the different glass categories. In fact, all of the categories fall into the RI range of the architectural glasses with the exception of the low RI headlight bracket. Often a visual inspection of the glass is used to say whether the fragment is from a container or a window i.e. the shape/curvature of the fragment is different. Once the glass examiner has determined that two samples are indistinguishable based on the RI, they will then use a database of RI values to obtain the frequency of occurrence of the glass having the particular RI in question (Koons & Buscaglia 2001). This method relies on the examiner having access to an accurate database of all known glass samples (Koons & Buscaglia 2001), this is often not practical. Also, many such forensic databases have only as much information as the glass types that have passed through the laboratory; and almost all glass databases are commercially confidential. Without access to a large study the databases can also be hard to substantiate (Tranter 2006). It is the usual practice in casework not to measure accurately the RI of glasses that do not match the control; a glass fragment is considered a match to the control if the measured RI falls within ± 3 standard deviations of the control mean (Harrison et al. 1985).

4.4.2 Density

Another method commonly used for the forensic analysis of glass particles is the measurement of the density of the glass. This is where a fragment of glass is placed into a liquid of approximately the same density and the density of the liquid is then varied by the addition of a miscible liquid which is more or less dense until the fragment of glass appears to 'float' i.e. not moving up or down the tube. It is at this point that the density of the liquid and the glass are equal and the density of the liquid can be measured and therefore the density of the glass determined (Curran et al 2000). The density of different glasses can vary greatly (Tranter 2006). Forensic scientists are not normally interested in determining the absolute density of a fragment but rather, in comparing the densities of two different fragments. This technique is good when large numbers of fragments need to be screened and those with similar densities can be sent for further

analysis (Howden 1981). Research has shown that there is a strong correlation between density and RI, but most forensic science laboratories have determined that the added discrimination of both techniques is not worth the extra cost of analysis (Curran et al 2000). In terms of both RI and density measurements, there is a lot of reliance on effectively one number to determine if two glasses are the same, and although there are statistics involved to determine the reliability of the measurement, other methods should be used to aid the discrimination of the samples (Trejos & Almirall 2005). Especially as both techniques rely on the comparison of the results with an existing database and these are often flawed in that they contain the data of the samples that have passed through the lab. Is a 'common' glass in the database actually a 'common' glass or is it just an unusual glass from a location that is frequently broken into? It is commonly believed that trace element concentrations are essential to enable the glass investigator to effectively compare and individualise the glass evidence (Zadora 2009).

4.4.3 Elemental Composition

"In the casework situation, however, the type of glass and the number and identity of the components is unknown and so a knowledge of the physical properties can give no firm indication of the composition" (Howden 1981: 20). The final category of analysis that is often employed in the forensic analysis of glass fragments is elemental analysis. Elemental analysis increases the value of the evidence when combined with conventional techniques such as RI (Trejos & Almirall 2004). There are several different methods that can and have been used to determine the chemical composition of a glass. Recent studies have shown that the elemental composition of modern glasses can vary significantly if the glasses have originated from different sources (Trejos & Almirall 2005). For example, light bulbs have been found to contain more potassium and/or barium than other types of glass (Zadora 2009). The analysis of major elements will yield little discrimination between the different samples; minor components of glasses are present in more variable proportions and it is these minor and trace elements that are useful in the discrimination of glass types (Howden 1981). Each distinct class of glasses has different manufacturing processes and therefore, they have different opportunities to include contamination of trace elements into the final product (Trejos & Almirall 2005). Essentially, elemental analysis can be used both to classify

glasses into type, and to discriminate between glasses of the same type that have similar physical characteristics (Curran et al 2000). Although RI differences are usually related to small compositional differences in the major elements of glass, it is possible to have two different glass samples and to be able to observe the same density and RI and yet measure variation within the minor or trace elements (Curran et al 2000). But, the elemental analysis of glass can suffer two main shortcomings; firstly, the process can be slow and destructive. The destructive nature of the analysis becomes an issue if the recovered fragments are few in number, because it is desirable that part of the evidence be retained for future examination. Secondly, some of the elemental techniques may require a relatively large amount of sample to get reliable readings (Curran 2003). In general, depending on the laboratory, the standard techniques used are RI and, if needed for extra discrimination, elemental analysis usually with the use of an SEM-EDS. Some facilities will use density measurements as well, but as has been previously mentioned the added discrimination of the using both RI and density analyses is not worth the extra cost. It is not recommended to rely on the use of one technique alone to either classify a glass into a category or to determine whether two samples of glass match. *“Results of [the] classification of [an] unknown glass fragment solely on the base of elemental composition, should be treated very carefully...due to the possible legal consequences of misclassification”* (Zadora 2007: 185).

Because the manufacture of modern vehicle glass in particular has been standardised in terms of the recipes used and the raw materials, on a localised scale there will be very little variation in the glass, whereas, on a larger scale there should be quite considerable variation as different manufacturers use raw materials from different sources. It is these variations used to create the same types of glass product in different factories that give rise to identifiable differences between the glasses. Also, although the industry has been standardised this does not mean that there is only one composition/method of production currently in use. In fact, there are over 700 different glass compositions in commercial use, but the number of compositions encountered in casework is usually quite small since the majority of glass has come from a small number of manufacturers (Hickman 1981). Because manufacturers intentionally control specific elements, it is the concentrations of these elements in glass that can be used to chemically characterise the source of the glass and the raw materials (FBI 2005a). Trace

elements which are important for the provenancing of glass are often not controlled by manufacturers except to keep them below levels that would impart undesirable properties to the glass (FBI 2005a). In particular, if a certain amount of recycled glass (cullet) is used in the glass batch, this can give rise to considerable variations in the trace element impurities, which can reflect the natural ores, used in the original glass (Tranter 2006). The impurities in cullet have increased in recent years due to the nature of glass products being recycled. For example, more heat resistant glass and ceramic glass is appearing in the market place for its use in modern cooker worktops. When this glass reaches the end of its life it is often recycled as cullet, but the oxides added to give the glass heat resistant properties act as potentially damaging impurities for other types of glass product (Unknown 2010). In cases where this cullet has been used, the forensic examiner is faced with a very confusing signature to the glass. It may be extremely hard to provenance the raw materials, but it may prove just as hard to classify the glass into a particular category.

4.4.4 Other Physical Properties

Once the flat glass is made, depending on its intended purpose, it is often further treated to improve the physical properties. For example, as the glass ribbons are cooled they can have wire mesh inserted, or the rollers can be used to impart a pattern onto the glass surface. Glass itself can be strengthened by two main methods, the first involves removing flaws in the glass and preventing new ones through the use of coatings; this only a short term technique as cracks will continue to develop. The second method involves placing the glass surface under compressive stresses to counter-act the tensile stresses inherent in the glass (Shelby 2005). Thermal tempering is a method that forms a compressive layer by using jets of cold air to rapidly cool the outer surface of the glass quicker than the core of the glass. The surface of the glass then comes under compression while the inner core will be in tension (Shelby 2005). Also, compressive coatings can be used on the glass to achieve the same effect (Shelby 2005). In the auto industry, coatings are also often added to the finished glass to improve the properties of the glass, for example, recent technology has developed 'self-cleaning' glass, where the coating repels water, causing the water droplets to run off the window (www.pilkington.com 2010). Therefore, it is in theory possible to determine where a

particular glass may have been manufactured based on the choice of raw materials used, but there is still the need to be able to determine from what object the glass originally came so that an appropriate control can be found. It is known that glass from car windows and modern building windows have very similar compositions (Zadora et al. 2010), due to the control over the raw materials and manufacturing processes already discussed. The most reliable scheme therefore for classifying glass samples into albeit arbitrary categories is to compare the analysis of an unknown sample with a reference collection of analyses of glasses of known origin (Hickman 1981). The classification of glass into use-type categories is a process which although arbitrary is necessary to forensic science. This process allows scientists to determine the potential source of control glass should this be lacking, and it also allows scientists to determine whether two glasses are likely to match, i.e. if they belong to different use-type categories they are not likely to be from the same source.

4.5 How Glass Fails

When broken glass is encountered in a forensic laboratory it is not always from a deliberate break. In some cases, glass can fail due to flaws in the glass itself. This may lead to a legal investigation if the manufacturer of the glass is accused of selling a faulty product. Depending on how a pane of glass has broken, this can tell forensic examiners from which direction the glass was broken and can give information about the nature of the crime. The origins of a failure can be classified as occurring from three sources: mechanical (handling, intentional indentation, finishing operations etc), processing (chemical and thermal), and intrinsic (defects in the structure which are inherent in specific glass manufacturing techniques) (Mecholsky 1994).

A common source of suspect glass is that which is recovered from clothing, this is usually because the suspect has broken a window or been involved with an incident where glass has been broken. In particular, when a hard object strikes a window, a mist of small fragments is ejected in the opposite direction to the blow (Howden 1981). The struck glass initially fractures at the far surface which is under tension, and as the cracks spread radially across the surface under compression small fragments of glass are ejected in the opposite direction to the blow. A large amount of glass will also travel in the same direction as the blow. The process by which the fragments are ejected

backwards from the window is normally referred to as 'backward fragmentation' (Pounds & Smalldon 1978). It is the transfer of these glass particles to a suspects clothing and the persistency with which these particles adhere to the clothing which is essential to its use as forensic evidence (Tranter 2006). The number of glass fragments retained on clothing reduces considerably during the first hour although particles have been found retained after eight hours (Tranter 2006). Footwear is likely to contain multiple fragments of glass from multiple sources (Becker et al. 2004); but not all of this glass will have come from the crime scene (Becker et al. 2004). Whereas, glass found on the clothing or hair of the suspect is more likely to have come from the crime scene (Zadora 2007). It is not unusual to find large numbers of non-matching glass fragments on the clothing of an individual suspected of criminal activity, although it is unusual to find more than three fragments of non-matching glass from the same source on the clothing of the individual (Lambert et al. 1995).

4.6 Car windows

The glazing of a car is not only integral to the functioning of the car, but it also offers a stylistic feature, and each piece of automotive glazing is unique to the specific vehicle opening for which it was designed (www.pilkington.com 2010). At the heart of the automotive glass design is the ability to impart a 3D shape to the glass together with increasing the strength and safety properties (www.pilkington.com 2010). Car windows are all manufactured using float glass, but they are treated in one of two ways, they are either toughened or laminated. Before this can take place the glass needs to be shaped and processed, especially in the case of toughened glass, because it is not practical to toughen the glass first. *"A thermally-tempered glass (a toughened glass) cannot be broken unless sufficient force is applied which will first overcome the compression at the surface and then introduce enough tension for breakage"* (Persson 1969: 96). In order to make the glass the correct shape for the vehicle it has to be heat treated, but there are a number of processes which must first be carried out before this can take place. The flat glass starts as a standard rectangular piece of auto float glass. The edges of this glass are shaped and smoothed while the glass is still flat. Then, any holes that may be required in the glass are drilled, and the glass is washed before the clean-room printing takes place. At this stage, the printing of any shade bands, logos, demisting

circuits, or integrated alarms or antennas occurs. The glass is then sent for shaping and strengthening (www.pilkington.com 2010). There are two methods of shaping the glass, the first heats the glass until it begins to 'sag' over a pre-defined mould or shape, relying mostly on gravity. The second method again heats the glass but this time presses it into shape between male and female moulds. The glass can then be toughened through a combination of controlled heating to very high temperatures ($>640^{\circ}\text{C}$) and differential cooling. Laminated glass is where two sheets of thin glass are sandwiched around a polyvinylbutyral (PVB) layer. The two layers of glass are usually shaped as matching pairs by either the 'sag' or press-moulding method and are then allowed to cool before the PVB layer is sandwiched in between. The PVB layer starts off opaque, the windscreen is heated to around 140°C under a pressure of $10\text{-}15\text{ kg/cm}^2$, and this process removes any trapped air, allowing the PVB to become transparent (www.pilkington.com 2010). The windscreen/window will then be sent to have glazing systems added. Glazing systems help to simplify the vehicle assembly process, and much of this work is carried out after lamination or tempering. This includes having the trim added to the window, which is shaped to fit precisely to the vehicle body. Also, locator clips and other trimmings such as rear-view mirrors may be added at this point. In other words, the glass manufacturer will supply the whole of the vehicle's windows created ready to be placed into the appropriate custom made space on the vehicle, rather than just providing simple pieces of glass.

In terms of car windows, standards relating to the glazing and light transmission in vehicles are available, for example, ISO 13837:2008 (International Standard), or BS 857:1967 (British Standard). Although glass will affect the angle at which light is refracted, many of the industry standards relate to the tints and films which may be applied to the windows. According to the British Standard (BS 857:1967) front windscreens can have no less than 70% Visible Light Transmission (VLT). One of the deciding factors in terms of the ability of the eye to detect objects is the contrast between the object and its background (Noy 2001). Loss of contrast can occur as light is transmitted through a medium (Noy 2001) but this is covered by the Modulation Transfer Function (MTF) and not the RI. If a pane of glass is flat, then the Modulation Transfer is not affected, whereas if the glass is curved it is. The extent to which the Modulation Transfer is affected also depends on the optical power being introduced

(Noy 2001). For example, on a bright sunny day, the contrast between objects is different to what it is on an overcast day. Tinted windows have a direct affect on the background luminance and therefore the contrast of the images (Noy 2001). The refractive index of the glass is not affected by changes in the curvature of the glass or by the tints and films applied to it, although, the tints and films will have their own RIs which may be different to that of the glass. Although the RIs of glass do vary, for soda-lime-silicate glass this is usually in the region of 1.4-1.7. The composition of the glass will not vary to the extent that the speed of light is slowed completely, and therefore, the RI will always be in this region. Therefore, the RI of the glass does not govern the VLT.

4.6.1 Who manufactures car windows

There are a large number of glass manufacturers across the world; these companies range in size and each has a number of plants specialising in different aspects of the glass manufacturing industry. Often these companies will be affiliated to each other or work with each other on joint projects. There are actually only about 4 major parent companies, the largest of these being the Asahi Glass Company (AGC) and Nippon Sheet Glass (NSG) both Japanese, followed by Saint Gobain (French) and Guardian (USA) (<http://www.glassonweb.com/articles/article/48/> 2010). These companies will share products and research through licensing agreements and the sales of shares, as well as through joint operations. For example, in 2000, Pilkington (a UK based company now part of NSG) and Glaverbel (a Belgian company now part of AGC), opened their joint owned Spanish 'float' plant. The companies joined forces and according to the agreement, Glaverbel would provide 60% of the productions and Pilkington would provide the other 40%. In return, Pilkington supplied Glaverbel with equivalent quantities of float glass in Northern Europe where Glaverbel had no float plant (www.pilkington.com 2010). In some cases, for commercial purposes, companies will also buy their competitors glass (Greenall 2007 pers. comm.).

Most small glass producers will specialise in the types of glass they make, for example, architectural glass or automotive glass. These smaller manufacturers also tend to supply their local domestic markets. The larger glass manufacturers will often have several different types of manufacturing plants, in several locations around the world. These companies will also often supply both the domestic markets and the international

markets (www.pilkington.com 2010). For example, Pilkington were involved with many different aspects of the glass manufacturing industry, from architectural and automotive glass to optical glass, and glass for electrical applications. In 1995, Pilkington Europe decided to split its business into three specific lines, automotive products, building products, and technical glass products.

Common brands of automotive glass encountered during the DA survey are listed in Table 4-4 along with the parent companies and the umbrella group to which the companies belong. It will be noticed that seven brands are classed as ‘Independent’, this is not a parent group but signifies that these companies all independently owned and operated. For four brands, Star Glass, Uniglas, Sitralit, and Luna Securit, no information could be found. This table is a simplification of the current situation, for example, Saint Gobain produces Sekurit glass, and the company HQ is in France, but manufacturing plants with the Saint Gobain name operate all over Europe. As mentioned before these are the brands that were encountered during the survey of cars; if a survey were undertaken in Asia then more Japanese, Taiwanese and Malaysian companies would be apparent.

Parent Group	Parent Company	Glass Brand	Country of Origin
AGC	Asahi Glass Co.	AGC Automotive	Japan
AGC	Asahi Glass Co.	Temperlite - Asahi	Japan
AGC	Asahi Glass Co.	Lamisafe - AGC	Japan
AGC	Asahi Glass Co.	Lamilex - Asahi	Japan
AGC	Asahi Glass Co.	Lamisafe - Asahi	Japan
AGC	Glaverbel	Splintex	Belgium
AGC	PPG Industries	PPG	USA
AGC	Duplate	Armourplate	Canada
Guardian	Guardian Industries	Guardian	USA
Independent	Auto Windscreens Ltd	RAC Auto Windscreen	UK
Independent	Fuyao Group	FUYAO	China
Independent	General Motors	GM Tempered	USA
Independent	Keumkang Chemical Co.	Keumkang	Korea
Independent	PG Glass	Armourplate	South Africa
Independent	PG Glass	Safevue	South Africa
Independent	Soliver	Soliver	Europe
NSG	Nippon Sheet Glass	Nippon Safety	Japan
NSG	Nippon Sheet Glass	Therlite - T - Nippon Safety	Japan
NSG	NSG	Pilkington	UK
NSG	Pilkington	Triplex	UK
NSG	Pilkington	United LN Glass	USA
NSG	Pilkington	NordLamex	Finland
NSG	Societa Italiana Vetro Siv	Sicursiv	Italy

	S.P.A. - Pilkington		
NSG	Vitro - Pilkington	Crinamex	Mexico
Saint Gobain	Central Glass Co.	Carlex AS2	USA
Saint Gobain	Central Glass Co.	Tempalex	Japan
Saint Gobain	HanGlass	GMDAT HanGlass	Korea
Saint Gobain	Saint Gobain	Sekurit - Saint Gobain	France
		Star Glass	
		Uniglas	
		Sitralit	
		Luna Securit	

Table 4-4 Table of automotive glass manufacturers

4.7 Survey

“Cars are not necessarily fitted at the assembly stage with windows from only one manufacturer. For example, a 1971 Vauxhall Viva was known to have windows from three different manufacturers when new. Usually however, the presence of windows of more than one origin indicates that the vehicle concerned has had a replacement window fitted either because of accidental or malicious damage during its lifetime” (Renshaw & Clarke 1974: 313).

The second case-study of this thesis is about applying the forensic and archaeological techniques of provenancing to modern colourless glass. As this chapter has highlighted, the range of modern glass and its potential uses is large. In order to compare the techniques used, it was felt that window glass should be used in both studies. But, it was felt that there would be too much variation and not enough control over samples from architectural windows, i.e. it would be difficult to determine when a window had been installed and who had produced the window. For automotive glass this is made slightly easier by the provision of a stamp on the windows (Figure 4-5).

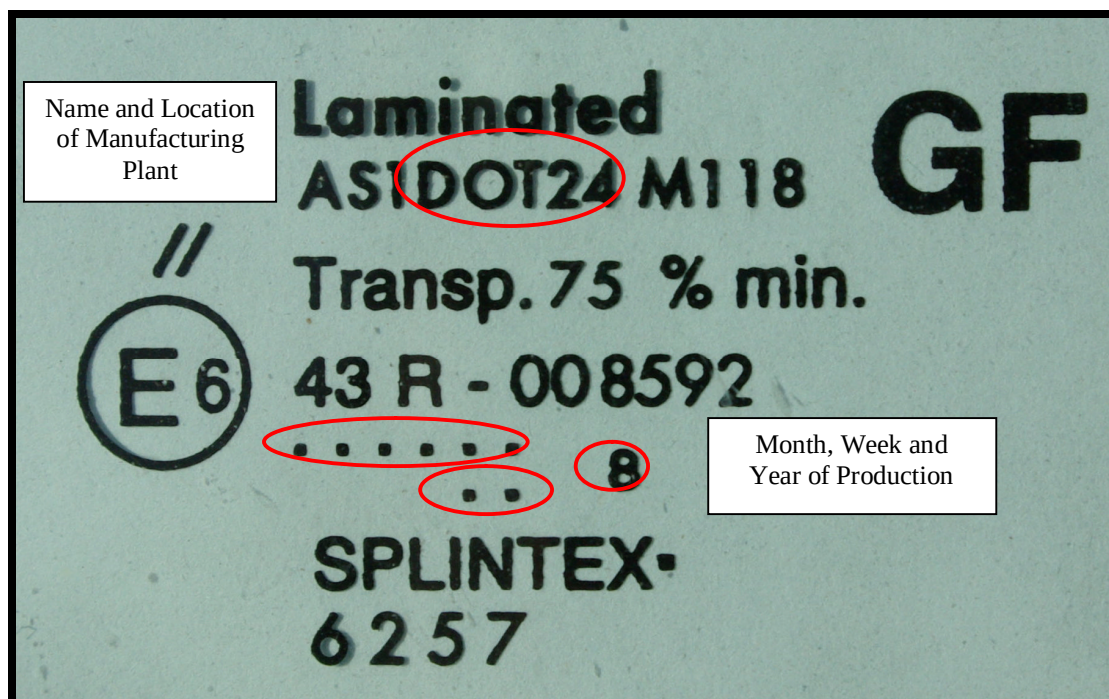


Figure 4-5 Stamp found on car windows

This stamp lists the details of the window manufacturer, and usually the month, year and sometimes week of production along with the country in which the manufacturing plant was located. For example, in Figure 4-5, the month of manufacture is represented by the series of six dots, the week of production is represented by the two dots beneath this, and the year of production is represented by the number to the right of the former. In this example, the glass was manufactured in the 2nd week of Jan 2008. The Dot number, in this case DOT24, relates to the manufacturing plant in which the glass was made, DOT24 is AGC Automotive Europe, located in Gilly, Belgium. The brand of this glass is Splintex, and it is laminated. In order to assess the frequency with which windows were replaced, and to determine whether there were any patterns in terms of which glass manufacturers provided the windows for which make/model of car in a given year, a survey of 300 cars was taken across the Defence Academy (DA).

The make and model of each vehicle was recorded along with the year of registration taken from the license plate if possible (some cars had personalised number plates making it impossible to record the year of registration). Each window of the vehicle then had the details from the stamp recorded. Not all of the windows had the name of the glass manufacturer on the stamp and it was not always possible to read all of the other information, for example, if the car window was slightly open, this often

obscured some of the information on the stamp and if the windows were tinted this could also pose a problem for reading the information.

One of the aims of the survey was to determine the frequency of window replacements. This was achieved by comparing the date of the windows in a vehicle to the date of the vehicle itself. Allowing for the fact that automotive windows can be kept in storage for up to six months (Greenall 2007 pers. comm.), a replacement window was therefore defined as being more than a calendar year in date from the license plate. For example, a vehicle dated by the license plate to be 2002 with a window dating to 2004, would be classed as having a replacement window. This method does not take into account any replacements that have occurred within a year of the car being registered; it also does not take into account the fact that a vehicle may have had the same window replaced several times. As this method relies on the license plate to give a date for the vehicle, some anomalies can occur. For instance, if all the windows on the vehicle show the same date and this is more than a year older than the license plate. In this case it is probable that the license plate has is personalised or has been transferred from another vehicle for various reasons. A second potential anomaly is if the windows all predate the license plate date. In this case it is likely that the vehicle was sitting on a car lot after manufacture for some time before being registered.

33 different makes of car were recorded and the data from all six windows on the vehicle (in a small number of cases the vehicle was either a convertible, in which case three windows were recorded or it was a people carrier and up to eight windows were recorded). It soon became apparent that this number of makes of vehicle provided too much variation in terms of window manufacturer and also in some cases only one or two cars of that make were present on-site. It was therefore decided to focus the survey on five main car manufacturers, these being, Ford, VW, Vauxhall, Renault and Peugeot. By focussing on these five manufacturers it was hoped that a more detailed picture could be produced. Table 4-5 shows the results of the survey.

Make	Model	Year	Windscreen	Driver	F. Passenger	R. Driver	R.Passenger	R. Windscreen	Year
Audi	A3	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	2006 W
Audi	A3	2006	Guardian	SG	SG	SG	SG	Pilkington	
Audi	A4	2002	SG	SG	SG	SG	SG	SG	
Audi	A4	2002	SG	SG	SG	SG	SG	SG	
Audi	A4	2004	Guardian	SG	SG	SG	SG	SG	
Audi	A4	2009	SG	Pilkington	Pilkington	Pilkington	Pilkington	SG	
BMW	540	2000	Splintex	Sicursiv	Sicursiv	Sicursiv	Sicursiv	SG	
BMW	X3	2006	Guardian	SG	SG	SG	SG	Guardian	
BMW			Splintex	Splintex	Splintex	Splintex	Splintex	SG	
Chevrolet	Kalos	2005	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Chevrolet	Kalos	2005	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Chevrolet	Kalos	2005	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Chevrolet	Kalos	2006	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Chevrolet	Kalos	2006	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Citroën	AX		PPG	PPG	PPG	PPG	PPG	PPG	
Citroën	C2	2004	SG	SG	SG	SG	SG	SG	
Citroën	C3	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Citroën	C5	2003	Pilkington	SG	SG	SG	SG	SG	2007 W
Citroën	Saxo	2000	RAC Auto Windscreen	SG	SG	Splintex	Guardian	Splintex	
Citroën	Xsara	2003	SG	SG	SG	SG	SG	SG	2007 W
Daewoo	Matiz	2001	GMDAT	GMDAT	GMDAT	GMDAT	GMDAT	GMDAT	

			HanGlass	HanGlass	HanGlass	HanGlass	HanGlass	HanGlass	
Daewoo	Matiz	2003	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Daewoo	Matiz	2004	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Daewoo	Matiz	2004	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Daewoo	Matiz	2004	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Daewoo	Matiz	2004	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	GMDAT HanGlass	
Fiat	Brava	2001	Splintex			SG	SG	SG	
Fiat	Marea SX	1999	SG	Splintex	Splintex	Splintex	Sicursiv	Sicursiv	
Fiat	Panda	2007	Pilkington		SG	SG	Pilkington		
Fiat	Punto	1998	Pilkington	PPG	PPG	PPG	PPG	Sicursiv	
Fiat	Seicento	2002	Pilkington	Pilkington	Pilkington	SG	SG	SG	2003 W
Fiat	Stilo	2001	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Escort	1992	SG	SG	SG	SG	SG	SG	2007 W
Ford	Escort	1993	Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Ford	Fiesta	1997	Triplex	Triplex	Armourplate	Triplex	Triplex	Triplex	
Ford	Fiesta		Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Ford	Fiesta	2000	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2001	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2001	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2002	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2003	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2003	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2003	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	2007 W
Ford	Fiesta	2003	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2003	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2004	Pilkington	Armourplate	Pilkington	Pilkington	Pilkington	Pilkington	

Ford	Fiesta	2004	SG	SG	SG	SG	SG	SG	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Ford	Fiesta	2009	Pilkington	AGC	AGC	AGC	AGC	Pilkington	
Ford	Fiesta - Ghia	1997	Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Ford	Focus	1999	SG	SG	SG	SG	SG	SG	
Ford	Focus	1999	SG	SG	SG	SG	SG	SG	
Ford	Focus	1999	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2001	SG	SG	SG	SG	SG	SG	
Ford	Focus	2002	SG	SG	SG	SG	SG	SG	
Ford	Focus	2002	SG	SG	SG	SG	SG	SG	
Ford	Focus	2004	SG	SG	SG	SG	SG	SG	
Ford	Focus	2004	SG	SG	SG	SG	SG	SG	
Ford	Focus	2004	SG	SG	SG	SG	SG	SG	
Ford	Focus	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus - Ghia	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus - Ghia	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus - Ghia	2006	SG	SG	SG	SG	SG	SG	
Ford	Focus - Ghia	2006	SG	SG	SG	SG	SG	SG	

Ford	Ka	2000	Safevue	SG	SG	SG	SG	SG	
Ford	Ka	2000	Safevue	SG	SG	SG	SG	SG	
Ford	Ka	2001	RAC Auto Windscreen	SG	SG	SG	SG	SG	
Ford	Ka	2003	Guardian	SG	SG	SG	SG	SG	
Ford	Ka	2003	SG	SG	SG	SG	SG	SG	
Ford	Ka	2003	SG	SG	SG	SG	SG	SG	
Ford	Ka ²	1997	Pilkington	SG	SG	SG	SG	SG	
Ford	Mondeo	1997	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	1997	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	1998	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	1998	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	2002	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	2004	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	2004	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	2004	SG	SG	SG	SG	SG	SG	
Ford	Mondeo	2004	SG	SG	SG	SG	SG	SG	
Ford	Mondeo -Ghia	2002	SG	SG	SG	SG	SG	SG	
Ford	Mondeo -Ghia	2002	SG	SG	SG	SG	SG	SG	
Ford	Mondeo -Ghia	2002	SG	SG	SG	SG	SG	SG	
Ford	Mondeo -Ghia	2002	SG	SG	SG	SG	SG	SG	
Ford	S-Max	2008	Pilkington	SG	SG				
Honda	Accord	1993	Lamisafe - Asahi	Temperlite - Asahi	Armourplate	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	
Honda	Civic	2001	Safevue	SG	SG	Splintex	Splintex	Splintex	
Honda	Civic	2008	Pilkington	AGC	AGC	AGC	AGC	Pilkington	
Honda	Civic	2009	Pilkington	SG	SG	SG	SG	Pilkington	
Honda	Jazz	2006	Nippon Safety	Nippon Safety	Nippon Safety	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	
Hyundai	Accent	1997	Keumkang	Keumkang	Keumkang	Keumkang	Keumkang	Keumkang	

Hyundai	Coupe	1997	HMC Keumkang	HMC Keumkang	HMC Keumkang	HMC Keumkang	HMC Keumkang	HMC Keumkang	
Jaguar	X-type	2004	SG	SG	SG	SG	SG	SG	
Jaguar	XJR		Safevue	Triplex	Triplex	Triplex	Triplex	Triplex	
Kia	Sportage	2007	SG	SG	SG	SG	SG	SG	
Land Rover	Freelander	2002	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	2007 W
Land Rover	Freelander	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Land Rover	Range Rover		Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Land Rover	Turbo	1989		Sicursiv	Sicursiv			Sicursiv	
Land Rover		1999	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Land Rover		2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Lexus	LS430			Lamisafe - Asahi	Lamisafe - Asahi	Lamisafe - Asahi	Lamisafe - Asahi		
Lexus	IS200	2000	Pilkington	Temperlite - Asahi	Nippon Safety	Temperlite - Asahi	Nippon Safety	Nippon Safety	
Mazda	MX S	1998	Nippon Safety	Nippon Safety	Nippon Safety			Nippon Safety	
Mercedes	SL350	2003	SG	SG	SG	SG	SG	SG	
Mercedes	C200 - Kompressor	2002	PPG	PPG	PPG	PPG	PPG	PPG	
MG		2000	Pilkington	Pilkington	Pilkington				2005 W

Mini	Cooper S	2004		Splintex	Splintex	SG	SG	Splintex	
Mitsubishi	Colt	2005	SG	Splintex	Splintex	Splintex	Splintex	Splintex	
Mitsubishi	FTO	1994	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi			Temperlite - Asahi	
Mitsubishi	FTO	1994	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	
Nissan	Almera	1996	AGC	Carlex AS2	Carlex AS2	Carlex AS2	Carlex AS2	Carlex AS2	
Nissan	Almera	1997	Safevue	Carlex AS2	Carlex AS2	Carlex AS2	Carlex AS2	Temperlite - Asahi	
Nissan	Almera	1999	Carlex AS2	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	United LN Glass	
Nissan	Almera	1999	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	Temperlite - Asahi	
Nissan	Micra	1998	Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Nissan	Micra	2004	Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Nissan	Note	2008	SG	SG	SG				
Nissan	Sunny		Triplex	Triplex	Triplex	Tempalex	Triplex	Triplex	
Peugeot	205	1989	Soliver	Luna Securit	Luna Securit	Luna Securit	Luna Securit	Luna Securit	
Peugeot	206	1999	Guardian	SG	SG	SG	SG	Sicursiv	
Peugeot	206	2000	Splintex	SG	SG	SG	SG	Sicursiv	
Peugeot	206	2003	Splintex	Splintex	Splintex	Splintex	Splintex	Splintex	
Peugeot	206	2004	Splintex	SG	SG	Pilkington	Pilkington		
Peugeot	206	2006	Splintex	SG	SG	AGC	AGC	Pilkington	
Peugeot	207	2007	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2007	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2007	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	

Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	
Peugeot	207	2008	SG	SG	SG	SG	SG	Pilkington	
Peugeot	307	2005	Pilkington	Splintex	Splintex	Splintex	AGC	Guardian	
Peugeot	307	2005	Pilkington	SG	SG	SG	SG	Guardian	
Peugeot	307	2006	SG	SG	SG	SG	SG	Pilkington	
Peugeot	308	2008	Guardian	SG	SG	AGC	AGC	AGC	
Porsche	Cayenne S	2002	Guardian	SG	SG	SG	SG	SG	2004
Porsche			SG	SG	SG	SG	SG	SG	
Renault	Clio	2002	Splintex	SG	SG	Splintex	Splintex		
Renault	Clio	2002	SG	SG	SG	Splintex	Splintex		
Renault	Clio	2003	SG	SG	SG	Splintex	Splintex	SG	
Renault	Clio	2003	SG	SG	SG	Splintex	Splintex	SG	
Renault	Clio	2008	SG	SG	SG	SG	SG	Pilkington	
Renault	Clio	2008	SG	SG	SG	SG	SG	Pilkington	
Renault	Espace	2004	SG	SG	SG	SG	SG	SG	
Renault	Espace	2004	SG	SG	SG	SG	SG	SG	
Renault	Espace	2004	SG	SG	SG	SG	SG	SG	2006 RW
Renault	Espace	2006	SG	SG	SG	SG	SG	SG	
Renault	Espace	2006	SG	SG	SG	SG	SG	SG	
Renault	Espace	2006	SG	SG	SG	SG	SG	SG	
Renault	Espace	2006	SG	SG	SG	SG	SG	SG	
Renault	Espace	2006	SG	SG	SG	SG	SG	SG	
Renault	Laguna	1998	PPG	SG	SG	PPG	PPG	SG	2001 W
Renault	Laguna	2003	Pilkington	Pilkington	Pilkington	SG	SG	SG	
Renault	Laguna	2009	SG	SG	SG	Star Glass	Star Glass	SG	
Renault	Megane	1997	SG	Splintex	Splintex	Splintex	Splintex	Splintex	

Renault	Megane	2005	SG	SG	SG	SG	SG	SG	2006 D
Renault	Megane	2005	SG	SG	SG	SG	SG	SG	
Renault	Scenic	2003	Splintex	Splintex	Splintex	Splintex	Splintex	SG	
Renault	Scenic	2003	Splintex	Splintex	Splintex	Splintex	Splintex	SG	
Renault	Scenic	2003	Splintex	Splintex	Splintex	Splintex	Splintex		
Renault		1998	PPG	SG	SG	PPG	PPG	SG	
Rover	416	1995	Safevue	Sicursiv	Sicursiv	Splintex	Splintex	Splintex	
Rover	Metro		Triplex	Triplex	Triplex	Triplex	Triplex	Triplex	
Saab	Aero	2008	SG	SG	SG	SG	SG	Guardian	
Saab	900SE	1997	SG	SG	SG	SG	SG	Pilkington	2002 RD
Seat	Alhambra	2005	SG	SG	SG	SG	SG	SG	
Seat	Altea	2008	Pilkington	SG	SG	SG	SG	Star Glass	
Skoda	Fabia	2002	SG	SG	SG	Splintex	Splintex	Splintex	
Skoda	Fabia ²	2008	AGC	SG	SG	SG	SG	SG	
Skoda	Octavia	2005	Splintex	Splintex	Splintex	Splintex	Splintex	Pilkington	
Smart	Forfour	2006	Splintex	Splintex	Splintex	Splintex	Splintex	Splintex	2004
Subaru	Forester	2001	Pilkington	Tempalex	Tempalex	Tempalex	Tempalex	Tempalex	
Subaru	Forester	2001	Lamilex - Asahi	Tempalex	Tempalex	Tempalex	Tempalex	Tempalex	
Suzuki	Swift			SG	SG	SG	SG	Pilkington	
Toyota	Avensis	2000	Triplex	Splintex	Splintex	Pilkington	Pilkington	Splintex	
Toyota	Avensis	2000	RAC Auto Windscreen	Splintex	Splintex	Pilkington	Pilkington	Splintex	2001 RW

Toyota	Avensis	2008	Pilkington	Splintex	Splintex	Splintex	Splintex	SG	
Toyota	Avensis	2008	Pilkington	Splintex	Splintex	Splintex	Splintex	SG	
Toyota	Celica	2005	AGC	Temperlite - Asahi	Temperlite - Asahi	Nippon Safety	Nippon Safety	Nippon Safety	
Toyota	Corolla	2003	AGC	Nippon Safety	Nippon Safety	Nippon Safety	Nippon Safety	Temperlite - Asahi	
Toyota	Yaris	2005	Splintex	SG	SG	SG	SG	Pilkington	
Toyota	Yaris	2008	Pilkington	Splintex	Splintex	Splintex	Splintex	SG	
Vauxhall	Astra	1997	Splintex	Soliver	Soliver	Guardian	Guardian	Splintex	2008 W
Vauxhall	Astra	1998	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	1998	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	1999	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	1999	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	1999	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	1999	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2000	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2000	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	2009 W
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2002	Safevue	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	2007 W
Vauxhall	Astra	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2005	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2006	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2006	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2006	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	

Vauxhall	Astra	2006	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Astra	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Astra	2008	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	
Vauxhall	Astra	2009	Guardian	Pilkington	Pilkington	Star Glass	Star Glass	Pilkington	
Vauxhall	Corsa	1995	Sicursiv	Sicursiv	Sicursiv	SG	SG	Sicursiv	
Vauxhall	Corsa	1996	Sicursiv	Sicursiv	Sicursiv	SG	SG	Sicursiv	
Vauxhall	Corsa	2001	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2001	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2002	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2004	Pilkington	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2004	Pilkington	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2004	Pilkington	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2005	Pilkington	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2005	Pilkington	Pilkington	SG	Pilkington	Pilkington	SG	
Vauxhall	Corsa	2007	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2007	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2007	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	

Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Corsa	2008	SG	SG	SG	SG	SG	SG	
Vauxhall	Insignia	2009	AGC	FUYAO	FUYAO	FUYAO	FUYAO	AGC	
Vauxhall	Meriva	2006	PPG	GM Tempered GS	GM Tempered GS		PPG	PPG	
Vauxhall	Nova	1991	Sicursiv	SG	SG	SG	SG	Sicursiv	
Vauxhall	Nova	1992	Sicursiv	SG	SG	SG	SG	Sicursiv	
Vauxhall	Vectra	1998	SG	SG	SG	SG	SG	SG	
Vauxhall	Vectra	1998	SG	SG	SG	SG	SG	SG	
Vauxhall	Vectra	2001	Splintex	Sicursiv	Sicursiv	Sicursiv	Sicursiv	Splintex	
Vauxhall	Vectra	2001	Splintex	Sicursiv	Sicursiv	Sicursiv	Sicursiv	Splintex	
Vauxhall	Vectra	2008	Pilkington	SG	SG	Pilkington	Pilkington	Splintex	
Volvo	940SE	1991	Safevue	SG	SG	SG	SG	SG	Sweden
Volvo	940	1996	Pilkington	SG	SG	SG	SG	SG	Sweden
Volvo	S70		Guardian	Pilkington	Pilkington	SG	SG	Pilkington	Sweden
VW	Golf	1991	Nordlamex	Sitralit	Uniglas	Uniglas	Uniglas	Splintex	1996 W
VW	Golf	1996	Sicursiv	Sicursiv	Armourplate	Sicursiv	Sicursiv	SG	2004 W
VW	Golf	2000	SG	SG	SG	SG	SG	SG	
VW	Golf	2002	SG	SG	SG	SG	SG	SG	
VW	Golf	2002	Sicursiv	Splintex	Splintex	SG	SG	SG	2006 W
VW	Golf	2005	SG	SG	SG	SG	SG	SG	
VW	Golf	2006	SG	Star Glass	SG	SG	Star Glass	SG	
VW	Golf	2007	SG	SG	SG	SG	SG	SG	
VW	Golf	2007	SG	SG	SG	SG	SG	SG	
VW	Golf	2007	SG	SG	SG	SG	SG	SG	
VW	Golf	2008	SG	Crinamex	Crinamex	Crinamex	Crinamex	Crinamex	
VW	Golf	2008	SG	Crinamex	Crinamex	Crinamex	Crinamex	Crinamex	
VW	Passat	2004	Pilkington	Soliver	Soliver	Soliver	Splintex	SG	2006 W

VW	Polo	1992	Nordlamex	Sicursiv	Pilkington	SG	SG	SG	
VW	Polo	1996	Pilkington	SG	SG	SG	SG	SG	
VW	Polo	1996	Pilkington	SG	SG	SG	SG	SG	
VW	Polo	2002	SG	SG	SG	SG	SG	SG	
VW	Polo	2002	SG	SG	SG	SG	SG	SG	
VW	Polo	2002	SG	SG	SG	SG	SG	SG	
VW	Polo	2004	SG	SG	SG	SG	SG	SG	
VW	Polo	2004	SG	SG	SG	SG	SG	SG	
VW	Polo	2009	SG	FUYAO	FUYAO	Armourplate	Armourplate	SG	
VW	Sharan	2001	SG	SG	SG	SG	SG	SG	
VW	Sharan	2001	SG	SG	SG	SG	SG	SG	
VW	Sharan	2001	SG	SG	SG	SG	SG	SG	
VW	Tiguan	2008	Pilkington	SG	SG	SG	SG	Pilkington	
VW	Tiguan	2008	Pilkington	SG	SG	SG	SG	Pilkington	
VW	Touran	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Splintex	
VW	Touran	2007	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington	Splintex	
VW		2007	Guardian	Soliver	Soliver	SG	SG	Guardian	

Table 4-5 Auto Survey across the DA

The survey of 300 cars resulted in 1791 windows being recorded (not all the vehicles had 6 windows). Of this, 20 windows (1%) were discovered to be replacements; 75% of these were windscreen replacements. The main producers (Figure 4-6) of the glass surveyed were Saint Gobain (SG) who made 48% of the windows; this was followed by Pilkington who produced 24%.

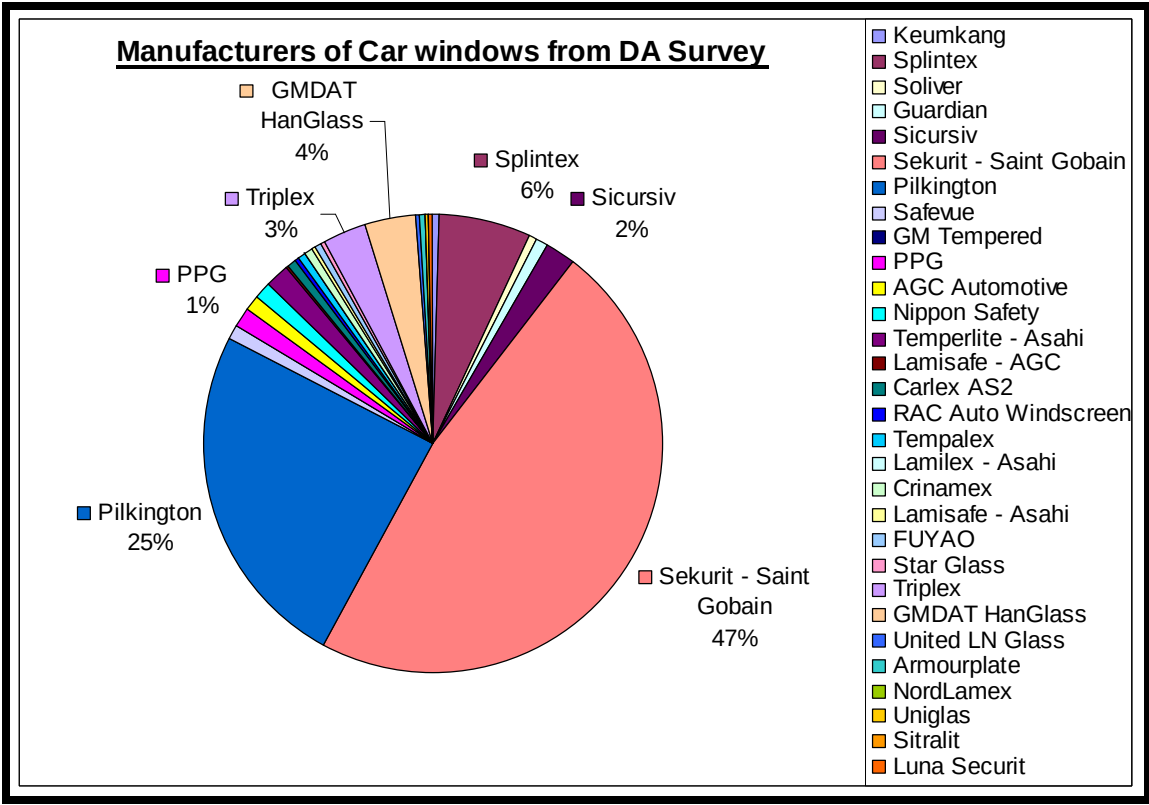


Figure 4-6 Percentages of glass manufacturers surveyed across the DA

By placing these manufacturers into their parent companies (Figure 4-7) it can be seen that the largest producer of glass for the cars surveyed is Saint Gobain (47%), the next largest is the Nippon Sheet Glass (NSG) group (28%). The Asahi Glass Company (AGC) group and the group made up of all the independent manufacturers both supply 12% of the glass.

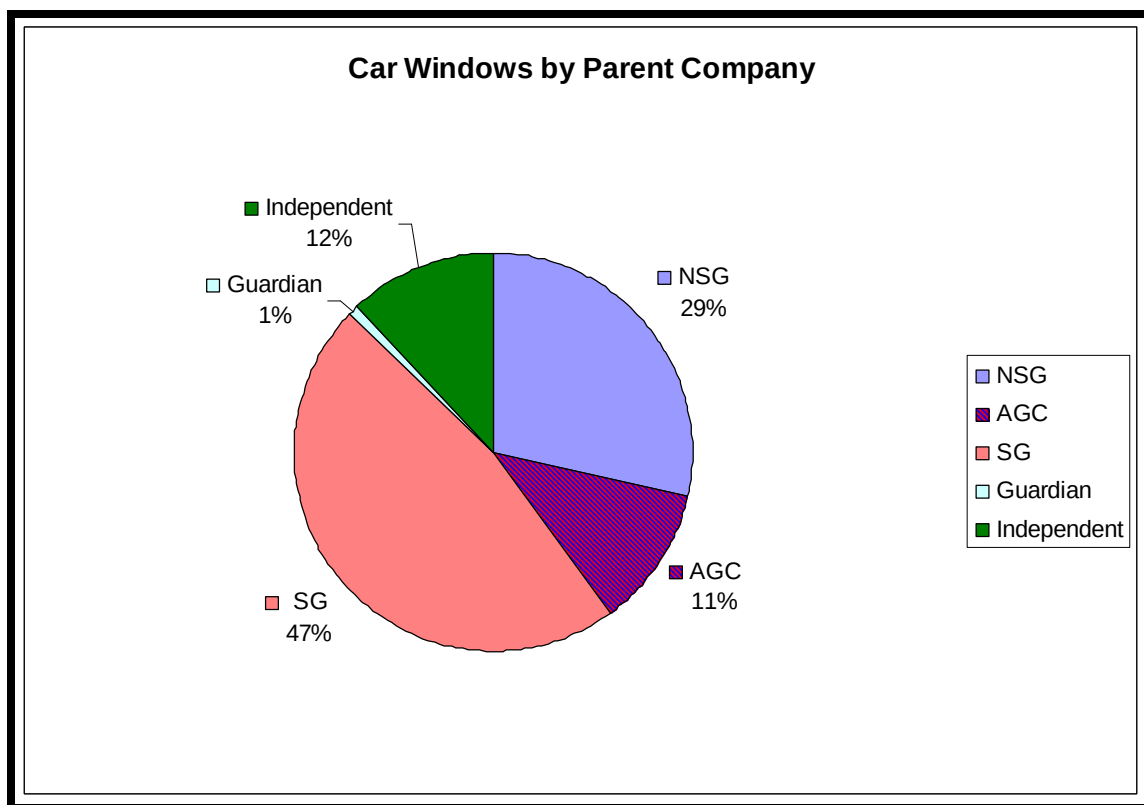


Figure 4-7 Percentages of car glass surveyed across the DA based on parent companies

4.7.1 Sole Use of Specific Glass Manufacturer

Of the 33 makes surveyed, not counting makes where only one car was recorded, 6 brands appear to use one specific glass manufacturer (Table 4-6).

Make	No. of Cars	Glass Manufacturer	Additional Information
Hyundai	2	Keumkang	
Subaru	2	Tempalex	Except windscreens
Land Rover	6	Pilkington	Land Rover Turbo 1989 Sicsurv
Daewoo	6	GMDAT HanGlass	
Chevrolet	5	GMDAT HanGlass	
Porsche	2	Saint Gobain	Except one windscreen

Table 4-6 Car manufacturers with single glass suppliers

Hyundai is a Korean company founded in 1947, and Keumkang is a Korean glass manufacturer, therefore, this suggests that the Korean automotive and glass manufacturers are working quite closely together. Tempalex is a brand name that describes the thermal toughening of the glass, the company that owns the Tempalex brand is the Central Glass Co. Ltd (a Japanese firm), but because the brand is also the name of the technique other companies sometimes use the term 'Tempalex' as part of

their name. As Tempalex is a method for toughening the glass, this may explain why the windscreens of the Subarus are from different glass manufacturers (toughened glass only being used on the sides and rear windscreen). Subaru is a subsidiary of Fuji Heavy Industries and this company has strong links with General motors (GM), Nissan and Toyota; because of this, many Subaru cars have components from the other companies (www.fhi.co.jp/english/index.html 2010). Land Rover was first produced in 1948 and has had a variety of owners over the years including, Rover, British Leyland and British Aerospace. Land Rover is currently owned by the Ford Motor Company. Pilkington are a British based glass manufacturer and have also had early links with the Ford Motor Company, and this may explain the preference for Pilkington glass within Land Rover vehicles. The Daewoo Matiz and Chevrolet Kalos are both from Korean based branches of GM, and HanGlass is again, a Korean glass manufacturer. Porsche is a German based company founded in 1931 by Ferdinand Porsche who also founded Volkswagen; Saint Gobain is a European glass manufacturer, originally a French company it now has plants all over Europe. Unfortunately on all the cars mentioned in Table 4-6 the DOT No. information was unavailable which means that a country of origin for the glass plants cannot be ascertained.

4.7.2 Window Replacements

Make	Model	Year Registration No.	Anomalous Window	Year of Glass
Audi	A3	2005	windscreen	2006
Citroën	C5	2003	windscreen	2007
Citroën	Xsara	2003	windscreen	2007
Fiat	Seicento	2002	windscreen	2003
Ford	Escort	1992	windscreen	2007
Ford	Fiesta	2003	windscreen	2007
Land Rover	Freelander	2002	windscreen	2007
MG		2000	windscreen	2005
Renault	Laguna	1998	windscreen	2001
Vauxhall	Astra	1997	windscreen	2008
Vauxhall	Astra	2002	windscreen	2010
Vauxhall	Astra	2002	windscreen	2007
VW	Golf	1991	windscreen	1996
VW	Golf	1996	windscreen	2004
VW	Golf	2002	windscreen	2006

VW	Passat	2004	windscreen	2006
Renault	Espace	2004	rear windscreen	2006
Toyota	Avensis	2000	rear windscreen	2001
Renault	Megane	2005	driver	2006
Saab	900SE	1997	driver	2002
			rear driver	2003
Porsche	Cayenne S	2002	all windows?	2004
Smart	Forfour	2006	all windows	2004

Table 4-7 Replacement windows encountered during survey of 300 cars

Of the 300 cars surveyed across the DA, 16 had replacement windscreens, 2 had replacement rear windscreens, 2 had replacements driver windows, and 1 had a replacement rear driver window (Table 4-7). There were also two anomalous vehicles, a Porsche Cayenne S, and a Smart Fourfor. The Porsche appears to have had all of its windows replaced in 2004, and the Smart car's windows predate the car itself. The latter of these, the Smart car, was probably sitting as a new car on a 'lot' for two years before being registered. This may in turn reflect the popularity of this vehicle, and this may be a trend which could be reflected in more recent times with the changing economic situation. The Porsche is harder to explain, it may be that through vandalism or an accident all the windows in the vehicle needed replacing. But, what is more likely is the owner of the vehicle decided for whatever reason to transfer his/her previous license plate, for personal or sentimental reasons. The way to determine which the correct hypothesis is would be to either ask the owner, or to check the (Vehicle Identification Number) VIN of the vehicle body parts and then determine more accurately the date of the vehicle.

The Saab 900SE is likely to have been involved in some form of accident, for both the driver and the rear driver windows to have been replaced; whereas, the Renault Megane is more likely to have been the target of either theft or vandalism, as only the driver window has been replaced. The majority of the replacements are windscreen replacements and this is a very common occurrence, a small chip caused by stone flying up from the road, can easily propagate into a crack. A chip in a windscreen can be relatively easily repaired with the injection of resin, which has a RI to match the windscreen, whereas a crack will usually result in the need to replace the entire window. Rear windscreen replacements are again more difficult to explain, they could be caused by either intentional or accidental damage.

It will be noticed that in four cases, the year of the vehicle licensing and the year of the window replacement are only a year apart. In each of these cases, the vehicle was licensed in the earlier part of the year, and had windows dating from the end of the previous year (windows are not usually stored in warehouses etc for more than c.6 months (Greenall 2007 pers. comm.)), the date of the replacement was therefore in the year following the licensing of the car but potentially up to two years after some of the other windows have been made and installed in the vehicle.

4.7.3 Ford

In terms of the Ford manufactured cars surveyed, the majority of the glass was manufactured either by Pilkington or St Gobain. Some of the earlier Fiestas and Escorts i.e. licensed 1993-1997, have mostly Triplex glass. But, all Triplex glass is manufactured by Pilkington (Renshaw & Clarke 1974); this is because Pilkington is a major shareholder in Triplex. Therefore, of 21 Ford Fiestas surveyed all have either all Triplex or all Pilkington windows with the exception of four (Table 4-8).

Make	Model	Year	Window	Manufacturer
Ford	Fiesta	1997	F. Passenger	Armourplate
Ford	Fiesta	2004	Driver	Armourplate
Ford	Fiesta	2004	All	St Gobain
Ford	Fiesta	2009	All Sides	AGC

Table 4-8 Non-Triplex or Pilkington windows in Ford Fiestas

Armourplate is the trade name of tempered glass manufactured by the Duplate Safety Glass Company of Canada, and the glass is approved for use anywhere in the vehicle except the windscreen, and it cannot be used in a vehicle for carrying passengers for hire (www.vsp.state.va.us/ 2010). A major shareholder of Duplate is PPG, one of the larger American glass manufacturers. But, a South African company called Shatterprufe (part of PG glass) also claim the brand Armourplate Toughened Glass. Therefore, without further information it would be impossible to say which brand of Armourplate had supplied the glass for these vehicles. The shatterprufe company claim to export automotive replacement glass, whereas the Duplate glass is an original product. Therefore, if the windows have been replaced they may have been supplied by the South African Shatterprufe company.

All of the Ford Focus cars surveyed licensed between 1999 and 2006 all contained St Gobain windows, the same was also true of all 13 Ford Mondeos surveyed, and they ranged in date from 1997-2004. Seven Ford Ka vehicles were surveyed, and all the windows were St Gobain, with the exception of five windscreens (Table 4-9). Safevue are supplied by Shatterprufe, which suggests that these windscreens may be replacements, in the same way RAC Auto Windscreens is the windscreen repair company of the RAC.

Make	Model	Year	Window	Manufacturer
Ford	Ka ²	1997	windscreen	Pilkington
Ford	Ka	2000	windscreen	Safevue
Ford	Ka	2000	windscreen	Safevue
Ford	Ka	2001	windscreen	RAC Auto Windscreen
Ford	Ka	2003	windscreen	Guardian

Table 4-9 Ford Ka windscreen manufacturers

4.7.4 Nissan

Eight Nissan vehicles were surveyed (Table 4-10); the Almera cars from 1996 and 1997 were mostly filled with Carlex glass, with the exception of the windscreens and the 1997 rear windscreen. Carlex is a North American company a subsidiary of the Central Glass Company Ltd (a Japanese firm). The 1999 Almera cars are mostly filled with Temperlite glass, which is manufactured by Asahi (AGC). One of the 1999 Almeras has a Carlex windscreen and a United LN Glass rear windscreen. United LN is a part of Pilkington, located in America. Two Nissan Micras (1998, 2004) were recorded, both of which are filled with Triplex glass, a 2008 Nissan Note had St Gobain glass, and an undated Nissan Sunny had Triplex glass apart from the rear driver window which was Tempalex (Central Glass Co. Ltd.). It is unsurprising that the majority of the glass in the Nissan vehicles is of Japanese make, or a company affiliated with a Japanese manufacturer, as Nissan is a Japanese brand. The interesting exception is the Nissan Note, which appears to have St Gobain glass throughout.

Make	Model	Year	Window	Manufacturer
Nissan	Almera	1996	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	AGC Carlex AS2 Carlex AS2 Carlex AS2 Carlex AS2 Carlex AS2
Nissan	Almera	1997	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Safevue Carlex AS2 Carlex AS2 Carlex AS2 Carlex AS2 Temperlite - Asahi
Nissan	Almera	1999	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Carlex AS2 Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi United LN Glass
Nissan	Almera	1999	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi Temperlite - Asahi
Nissan	Micra	1998	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Triplex Triplex Triplex Triplex Triplex Triplex
Nissan	Micra	2004	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Triplex Triplex Triplex Triplex Triplex Triplex
Nissan	Note	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG
Nissan	Sunny		Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Triplex Triplex Triplex Tempalex Triplex Triplex

Table 4-10 Nissan vehicles

4.7.5 Peugeot

The Peugeots were more complicated, with a variety of glass manufacturers being used over the different models (Table 4-11). Nine Peugeot 207's surveyed, had St Gobain glass in all but the rear windscreen, which in all cases was Pilkington. Two Peugeot 307's were surveyed both from 2005, and both vehicles had Pilkington windscreens and Guardian rear windscreens, but all the side windows were different on each vehicle. The earliest Peugeot surveyed was a 1989 205, this turned out to have completely different windows to all the other Peugeots. The windscreen was by Soliver (a European manufacturer located in France and Belgium) who now supply only Audi, VW, BMW, GM Europe (Opel, Vauxhall, IBC), Skoda, Maserati, Ferrari, Porsche. The rest of the windows were Luna Securit, for which no information could be found, so it is unknown whether this is a now obsolete brand from a particular manufacturer, or whether Luna Securit was a manufacturer.

Make	Model	Year	Window	Manufacturer
Peugeot	205	1989	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Soliver Luna Securit Luna Securit Luna Securit Luna Securit Luna Securit
Peugeot	206	1999	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Guardian SG SG SG SG Sicursiv
Peugeot	206	2000	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex SG SG SG SG Sicursiv
Peugeot	206	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex Splintex Splintex Splintex Splintex Splintex

Peugeot	206	2004	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex SG SG Pilkington Pilkington
Peugeot	206	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex SG SG AGC AGC Pilkington
Peugeot	207	2007	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2007	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2007	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington

Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	207	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	307	2005	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Pilkington Splintex Splintex Splintex AGC Guardian
Peugeot	307	2005	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Pilkington SG SG SG SG Guardian
Peugeot	307	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Peugeot	308	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Guardian SG SG AGC AGC AGC

Table 4-11 Peugeot vehicles

4.7.6 Renault

The common glass found in the Renault vehicles was St Gobain or Splintex (Table 4-12), with the Espace models having St Gobain glass throughout. The two 2008

Clio models had Pilkington rear windscreens whereas the other Clios models had a mix of Splintex and St Gobain glass. An unknown model 1998 Renault had some PPG glass, along with a 1998 Laguna and a 2009 Laguna had some Star Glass, but due to the limited number of these cars surveyed it is unknown whether they represent one off examples or a large trend.

Make	Model	Year	Window	Manufacturer
Renault	Clio	2002	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex SG SG Splintex Splintex
Renault	Clio	2002	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG Splintex Splintex
Renault	Clio	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG Splintex Splintex SG
Renault	Clio	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG Splintex Splintex SG
Renault	Clio	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington
Renault	Clio	2008	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG Pilkington

Renault	Espace	2004	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2004	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2004	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Espace	2006	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG

Renault	Laguna	1998	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	PPG SG SG PPG PPG SG
Renault	Laguna	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Pilkington Pilkington Pilkington SG SG SG
Renault	Laguna	2009	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG Star Glass Star Glass SG
Renault	Megane	1997	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG Splintex Splintex Splintex Splintex Splintex
Renault	Megane	2005	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Megane	2005	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	SG SG SG SG SG SG
Renault	Scenic	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex Splintex Splintex Splintex Splintex SG
Renault	Scenic	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex Splintex Splintex Splintex Splintex SG

Renault	Scenic	2003	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	Splintex Splintex Splintex Splintex Splintex
Renault		1998	Windscreen Driver F. Passenger R. Driver R. Passenger R. Windscreen	PPG SG SG PPG PPG SG

Table 4-12 Renault Vehicles

4.7.7 Vauxhall

The majority of the Vauxhall Astra cars surveyed had Pilkington glass throughout (25 cars), the exceptions being the 1998 (2 cars), 1999 (4 cars), and 2002 (6 cars) models surveyed (Table 4-5), which all had Safevue windscreens; although none of these appeared to be replacements. Two of the 2008 Astra models had St Gobain glass throughout, and the 1997 and 2009 Astras had a range of glass manufacturers. The Vauxhall Corsas surveyed were either all St Gobain, or were combined with either Sicursiv or Pilkington. The Nova models had combinations of Sicursiv and St Gobain glass, while the 2001 Vectra models had Sicursiv and Splintex glass and the 2008 Vectra had some Pilkington glass. Table 4-13 lists the glass manufacturers linked to different Vauxhall models based on the results of this survey.

Model	Glass manufacturer
Astra	Splintex Soliver Guardian Safevue Pilkington St Gobain Star Glass
Corsa	Sicursiv St Gobain Pilkington
Insignia	AGC FUYAO
Meriva	PPG

	GM Tempered
Nova	Sicursiv St Gobain
Vectra	St Gobain Splintex Sicursiv Pilkington

Table 4-13 Vauxhall Glass Suppliers

4.7.8 VW

The VW brand cars again appear to have a large amount of St Gobain glass (Table 4-5). The 2000, one of the 2002, the 2005 and the 2007 model Golfs all have St Gobain throughout, but in most cases only one car from each year was surveyed, with the exception of 2007 and 2002. The other 2002 model Golf had a Sicursiv windscreen, Splintex driver and front passenger windows and the remainder being St Gobain windows. The 2008 model surveyed had Crinamex glass throughout with the exception of the windscreen which was St Gobain. Crinamex is a South American company and the safety glass they provide can be used anywhere in the vehicle except the windscreen (www.vsp.state.va.us/ 2010). The 2002, and 2004 Polos were St Gobain throughout, and the 1996 was St Gobain with the exception of the windscreen which was Pilkington. The 1992 Polo had a Nordlamex windscreen, a Sicursiv driver and Pilkington front passenger window with the remainder being St Gobain. While the 2009 Polo had St Gobain front and rear windscreens, Armourplate rear passenger and rear driver and FUYAO front passenger and driver windows. So, as with the Vauxhalls and the Renaults, the manufacturers of the VW windows vary not only from year to year, and model to model, but also within the same year and model. Table 4-14 lists the glass manufacturers linked to different VW models based on the results of the DA car survey.

Model	Glass Manufacturer
Golf	Nordlamex Sitalit Uniglas Splintex Sicursiv Armourplate St Gobain Star Glass Crinamex

Passat	Pilkington Soliver Splintex St Gobain
Polo	Nordlamex Sicursiv Pilkington St Gobain Armourplate FUYAO
Sharan	St Gobain
Tiguan	Pilkington St Gobain
Touran	Pilkington Splintex
Unknown Model	Guardian Soliver St Gobain

Table 4-14 VW Glass Manufacturers

4.7.9 Other Manufacturers

Other makes and models of car not discussed above did feature in the survey, but in many cases, only one vehicle of a particular model was surveyed and there was a large amount of variation in the manufacturers both within the vehicle itself and within the brand. The production and manufacture of vehicle windows is governed by economics, not just in the cost of obtaining the relevant raw materials, or transporting the glass between manufacturing plants. But, also in terms of which vehicle manufacturers will buy from which glass company.

4.8 Results

Samples of glass from car windows were collected from scrap yards and analysed using forensic and archaeological analytical techniques in an attempt to determine the provenance of the glass. It is accepted that the control of glass recipes and the purification of raw materials has led to a narrowing of the RIs within automotive glass and a lack of variation within the elemental compositions (Trejos & Almirall 2005). Based on this assumption, the samples chosen for this study were collected from a range of vehicles in an attempt to determine whether the samples of glass could still be

differentiated. By choosing a variety of samples attempts could also be made at distinguishing patterns within the data. Table 4-15 lists the samples of automotive glass collected and analysed.

Sample	Make	Model	Year	Location of glass	Glass manufacturer	Dot No. location
AuAUD02	Audi	A4		Rear Driver		
AuBMW02	BMW		1991	Front Passenger		
AuCIT01	Citroën	Zantia	2000	Windscreen		
AuCIT02	Citroën	AX		Front Passenger	PPG	France
AuDAE01	Daewoo	Luganza	1999	Windscreen		
AuFIA01	Fiat	Tipo	1988	Windscreen		
AuFIA02	Fiat	Tipo	1989	Sun Roof		
AuFOR01	Ford	Focus		Windscreen		
AuFOR02	Ford	Escort	1994	Rear Passenger		
AuFOR03	Ford	Transit	1996	Front Passenger		
AuFOR04	Ford	Fiesta		Front Passenger	Pilkington	UK
AuFOR05	Ford	Transit		Front Passenger	Pilkington	UK
AuNIS01	Nissan	Sunny		Front Passenger	Central Glass Co.	Japan
AuREN01	Renault	Clio	1999	Windscreen		
AuREN02	Renault		1992	Windscreen		
AuROV01	Rover		1993	Front Passenger		
AuROV02	Rover	Metro		Front Passenger	Pilkington	UK
AuTOY01	Toyota	Carina	1992	Windscreen		
AuVAU01	Vauxhall	Corsa		Windscreen		
AuVAU02	Vauxhall	Astra	1997	Windscreen	Guardian	USA
AuVW01	VW	Sharan	1997	Windscreen		
AuVW02	VW		1993	Rear Windscreen		
AuVW03	VW	Sharan	1998	Rear Passenger		
AuVW04	VW	Golf	1988	Front Passenger	Saint Gobain	Germany

Table 4-15 Tables of automotive samples

24 samples of auto glass were analysed using SEM-WDS, LA-ICP-MS, Isotopes and GRIM3 for RI. The SEM-WDS was used to provide information on the major and minor elements and the LA-ICP-MS provided trace element data. The isotope analysis was used to supplement the elemental data; and the RI analysis was used to determine how much information can be gained from a ‘forensic’ analytical technique. Figure 4-8 below shows the correlation between the SEM-WDS and the LA-ICP-MS illustrating that the two techniques are in agreement with each, i.e. the data is consistent. The full results can be found in Appendix B.

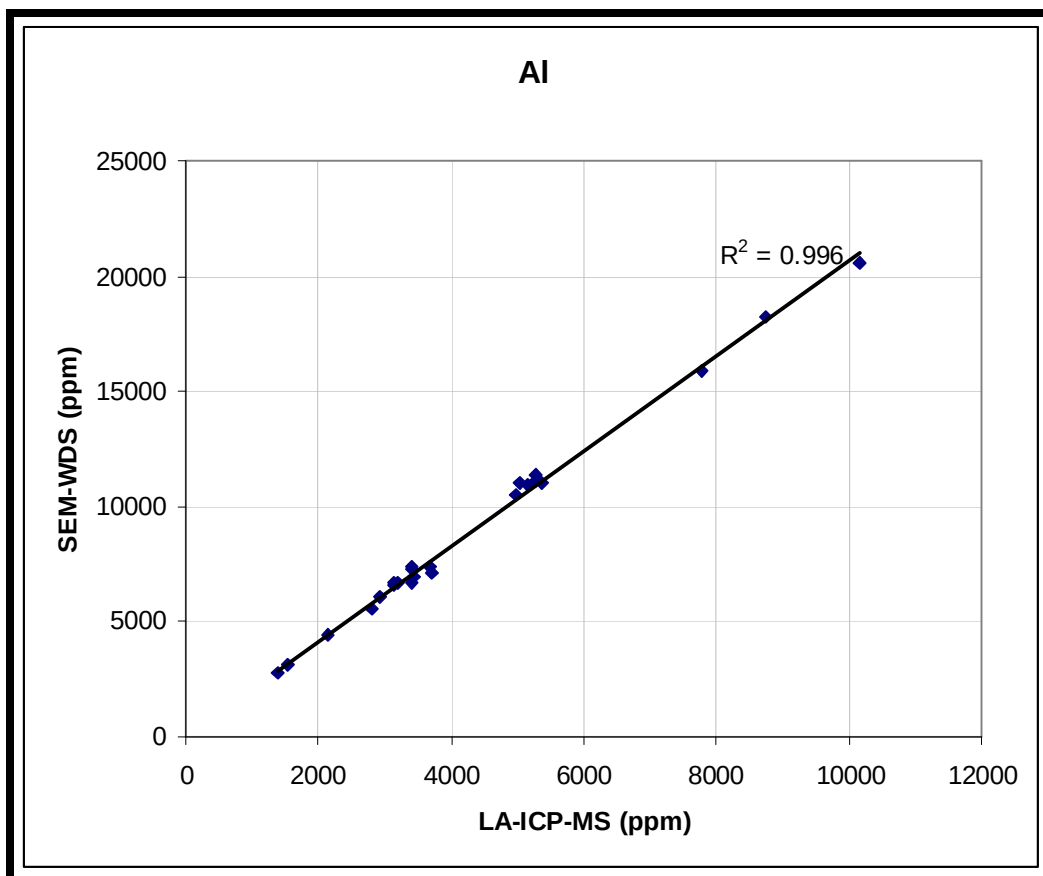


Figure 4-8 Plot of SEM-WDS aluminium (converted from wt% to ppm) against LA-ICP-MS aluminium

4.8.1 Refractive Index (RI)

The forensic technique of choice for glass analysis is RI (Coumbaros et al. 2008). 19 samples were tested to determine their RIs, and each sample had between 44 and 48 measurements recorded. The next step was to determine the similarity of these measurements to each other, to within three standard deviations of each sample mean. This was achieved by using the Student's t-test, which is used as standard (Curran et al 2000). Of 190 pairs (all the glass samples were compared to each other) all could be distinguished from one another with a confidence interval of 95%. This is illustrated in

Figure 4-9, although there appears to be some similarity between certain samples, they are all independent.

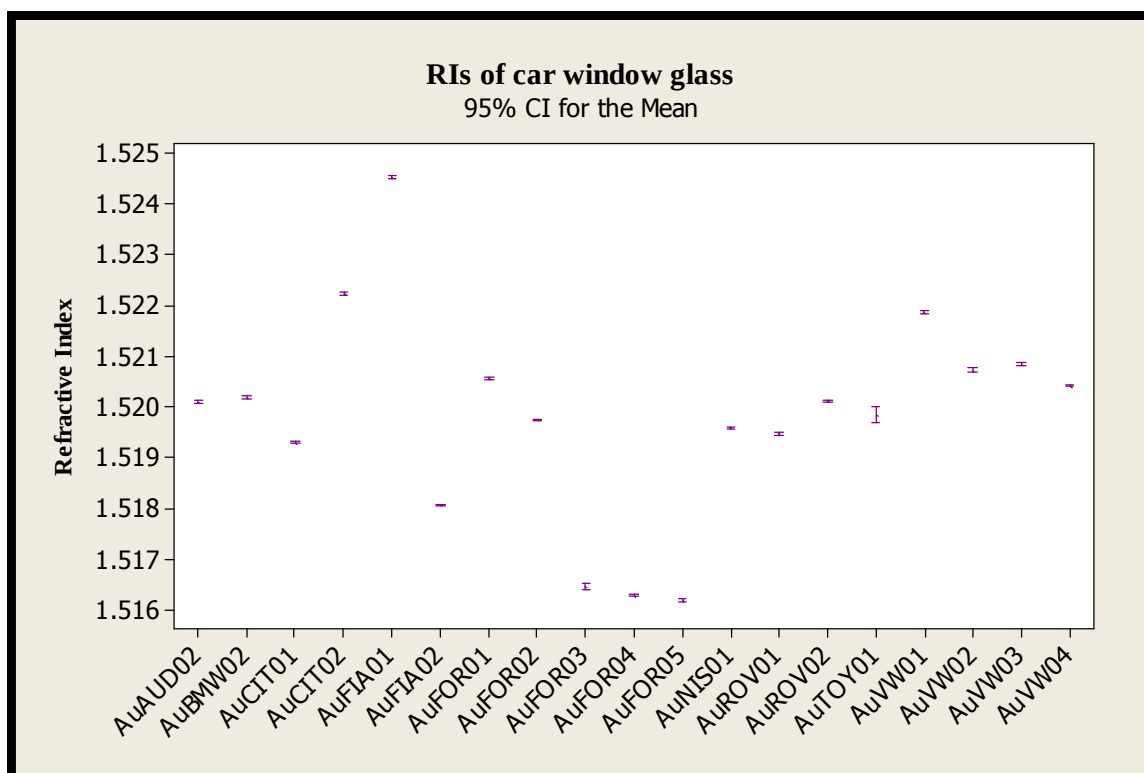


Figure 4-9 Plot of the RIs of the automotive samples

Three of the samples fall within the RI range for automotive windscreens (1.5130-1.5180) as defined by Foster and Freeman. These samples are AuFOR03, AuFOR04, and AuFOR05. All of the samples fall within the range of RIs for architectural glass (1.5080-1.5390), with all but one falling into the tighter architectural RI range of 1.5151- 1.5240; the exception to this is AuFIA01. A look at Table 4-15 will show that 10 of the samples were windscreen glass of these, five were analysed by RI (AuCIT01, AuFIA01, AuFOR01, AuTOY01, and AuVW01). The RI bracket defined by Foster and Freeman does not include any of them.

4.8.2 SEM-WDS

The results of the major elements show that the compositions of different types of auto glass are largely similar. CaO, SiO₂ and Na₂O in particular all fall within the expected 'norms' for auto glass, i.e. CaO between 8.38 and 9.94 wt%, SiO₂ between 68.59 and 71.05 wt%, and Na₂O between 12.60 and 13.79 wt%. The elements which show a certain amount of variation are K₂O, Al₂O₃ and FeO. The Al₂O₃ seems to split the data into three broad groups (<0.74 wt%, 1-1.15 wt% and >1.5 wt%). The FeO

content of the glasses appears to split the data into two groups (<0.12 wt% and >0.34 wt%). While the K_2O contents also split the data into two groups (<0.32 wt% and >0.53 wt%). But, there does not appear to be any consistency between specific car brands.

Although the major elements are showing a certain amount of consistency between the samples, other elements are showing a spread in the data. Although some potential groups may be forming there does not appear to be any consistency between specific brands of car, for example, not all Fords are grouping together. This suggests that either the pattern of individual glass manufacturers is beginning to emerge or, as is more likely, the economics of the supply and demand of the raw materials can be seen. Figure 4-10 shows three groups forming in terms of Al_2O_3 , it is interesting to note the three outlying samples AuDAE01, AuNIS01, and AuTOY01 are all Japanese manufactured vehicles and the Al_2O_3 content appears distinctly different to that of the other samples.

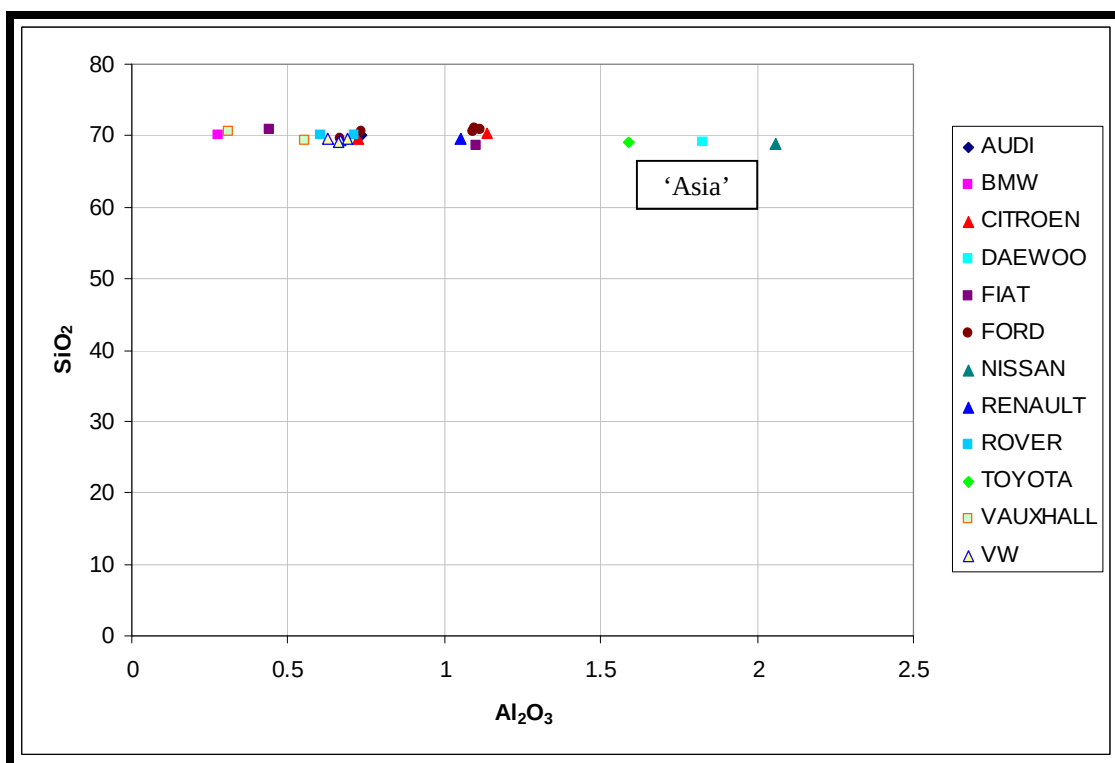


Figure 4-10 SEM-WDS graph of SiO_2 vs Al_2O_3 (wt%)

A comparison of the alkali components (Figure 4-11) appears to show a similar division, with the addition of three Fords (AuFOR03, AuFOR04 and AuFOR05) to the 'Asian' group. AuFIA01 is an outlying sample to both groups.

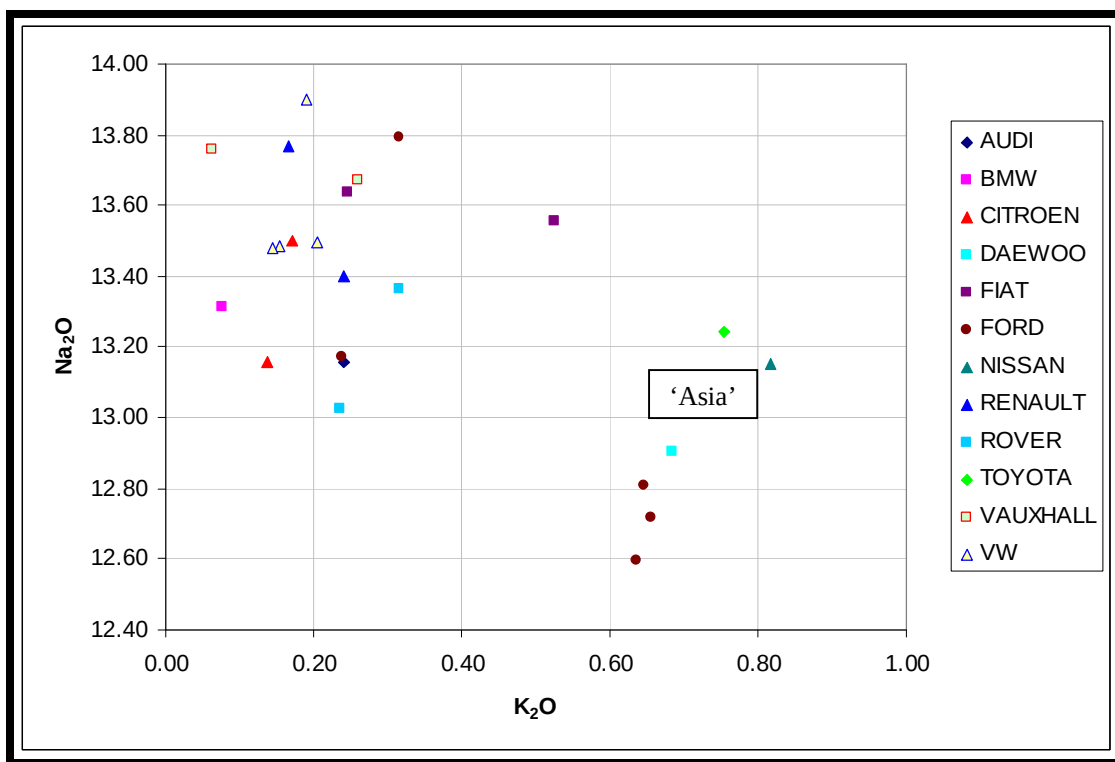


Figure 4-11 SEM-WDS graph of Na₂O vs K₂O (wt%)

A look at some of the more major elements within the glass shows the levels of control in terms of the overall recipes used, as the CaO and MgO contents show little distinction between the samples (Figure 4-12).

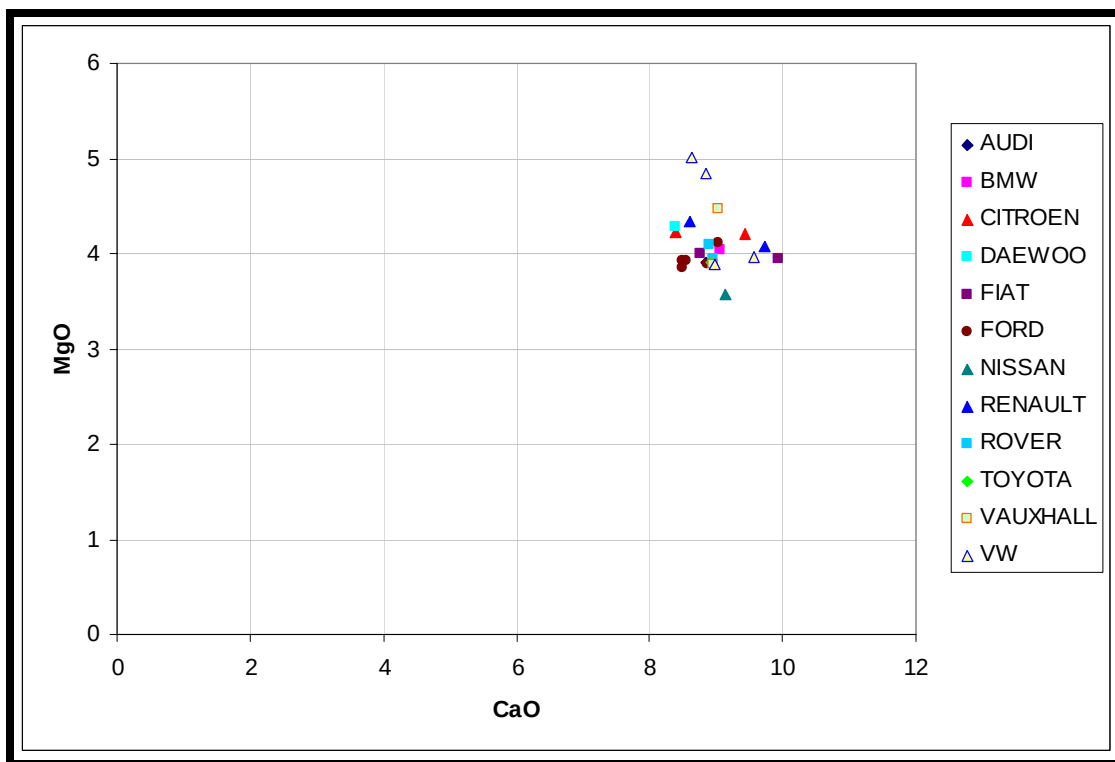


Figure 4-12 SEM-WDS graph of MgO vs CaO (wt%)

One of the greatest spreads of the data can be seen in Figure 4-13 which depicts FeO against Al_2O_3 . This graph also groups beginning to form within the data, noticeably three Ford samples (AuFOR03, AuFOR04 and AuFOR05), and the three 'Asain' samples again appear as outliers.

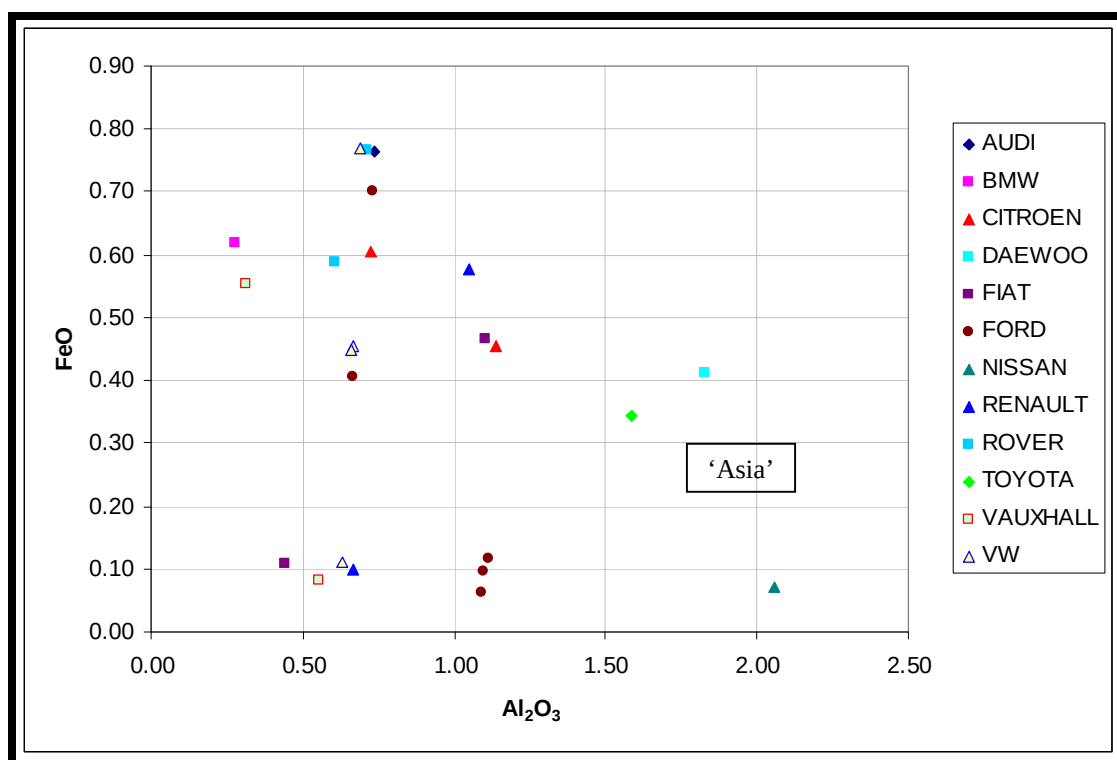


Figure 4-13 SEM-WDS graph of FeO vs Al₂O₃ (wt%)

From the results it can be seen that some of the samples of Ford glass are beginning to group and some of the samples of VW glass are occasionally beginning to group, but this is by no means definitive. The elements which appear to indicate the greatest spread of the data are Al₂O₃, K₂O and FeO. Although from the results groups can begin to be formed, these at present do not show a consistency; where a specific brand of car is beginning to group together, there are also other brands associated with it. One dispersed group that is beginning to form in the sense that the samples are consistently separated from the other samples, are the windows from Asian cars (Daewoo, Toyota, Nissan).

Due to the large number of variables in the data i.e. 22 oxides, Principal Component Analysis (PCA) was chosen to determine what the main influential variables on the data were, and these were subsequently used in cluster analysis to determine whether there were any underlying groups in the data that were not obviously visible. The results from the SEM-WDS were all standardised, and so a covariance matrix was chosen for this analysis. The results showed that the first five components could account for 98.1% of the data set, but, despite this only the first three components which have any real influence over the data (PC1 accounts for 47.5% of the data, PC2

accounts for 28.4% of the data, and PC3 accounts for 13% of the data). These Principal Components were then interrogated to determine which variables strongly related to these components. The range was from -1 to 1, a value close to -1 meant that the variable was negatively correlated with the component and a value close to 1 meant that the variable was strongly correlated. In this way, the variables which had the most influence over the data could be determined. Table 4-16 shows the variables which are strongly related to each of the first five principal components.

PC1	PC2	PC3	PC4	PC5
Al ₂ O ₃	CaO	MgO	Al ₂ O ₃	Na ₂ O
CaO	Na ₂ O		Na ₂ O	
SiO ₂			FeO	

Table 4-16 Variables strongly related to each Principal Component

SiO₂ was strongly negatively correlated with Principal Component 1 (PC1). The principal components highlighted as having the most influence over the data set in terms of the major and minor elements are the basic glass network formers and network modifiers. In particular the first three components which have the most influence comprise of network formers, flux and stabiliser. It is interesting to note that PC4 and PC5, both of which exert a lesser influence over the data also represent iron as having an influence, an impurity common in glass.

Cluster analysis was then performed using the most influential variables, as determined by the PCA analysis, to work out the clustering of the data. The first dendrogram produced (Figure 4-14) was used to determine the amount of logical groups that may have been present, i.e. by having the overall cluster go to 1 the analytical programme potentially forces groups together which may not be true groups.

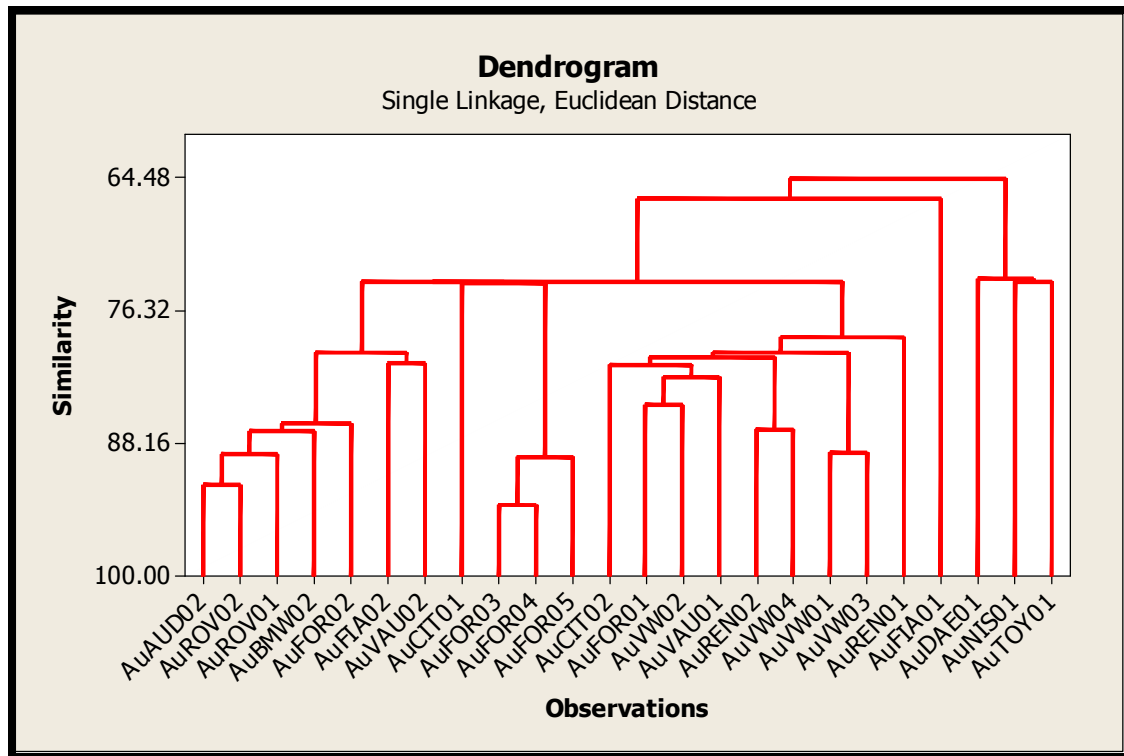


Figure 4-14 Dendrogram of potential groups based on Single Linkage and Euclidean Distance

Single linkage, chosen here, groups the clusters according to the ‘nearest neighbour’ principle i.e. the groups are chosen based on how close to each other the samples are when joined by a straight line. Ward linkage determines the clusters based on the sum of squared deviations between the points (Figure 4-15). This means that the clusters are based more on circular groups rather than straight lines. This method also tends to form clusters of roughly the same size.

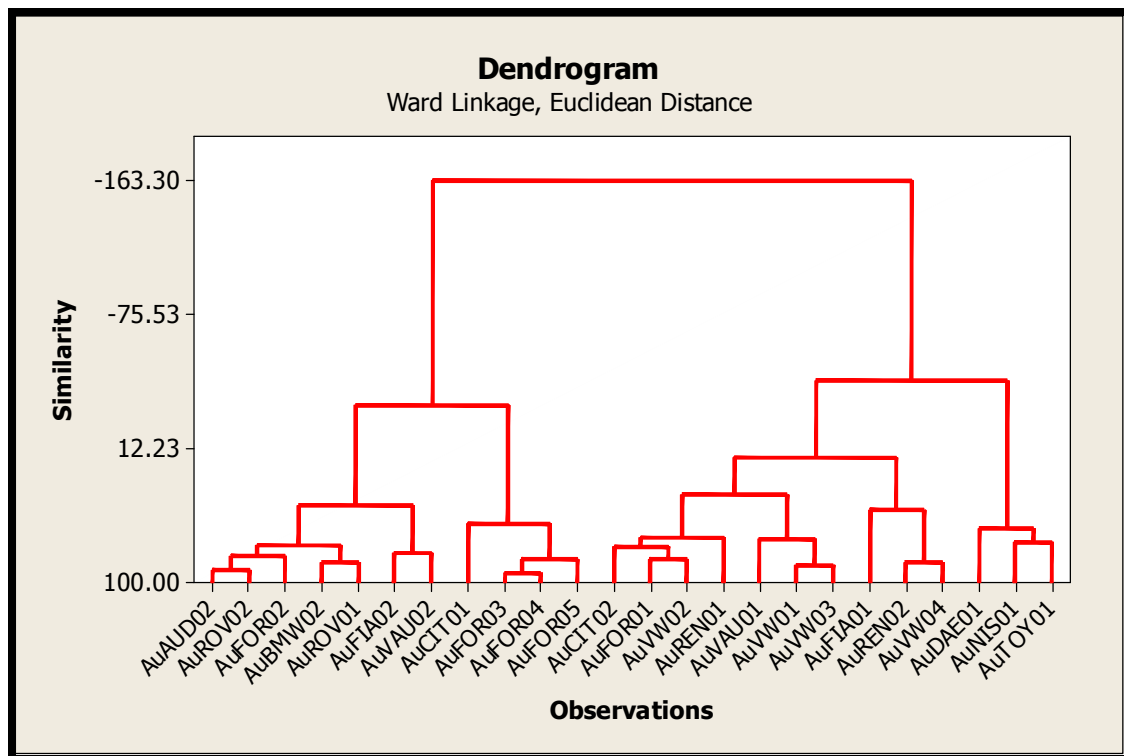


Figure 4-15 Dendrogram of potential groups based on Ward Linkage and Euclidean Distance

The reason two cluster methods were chosen is so that any samples which group consistently in both methods are more likely to be indicative of true groups and this minimises the influence of outliers in the data. Also, from these two charts it is possible to determine that the arbitrary point at which the groups seem to form is at a similarity level of 80%. Therefore, the cluster analysis was executed again with a level of 80% similarity as the cut of level for the groups (Figure 4-16 and Figure 4-17).

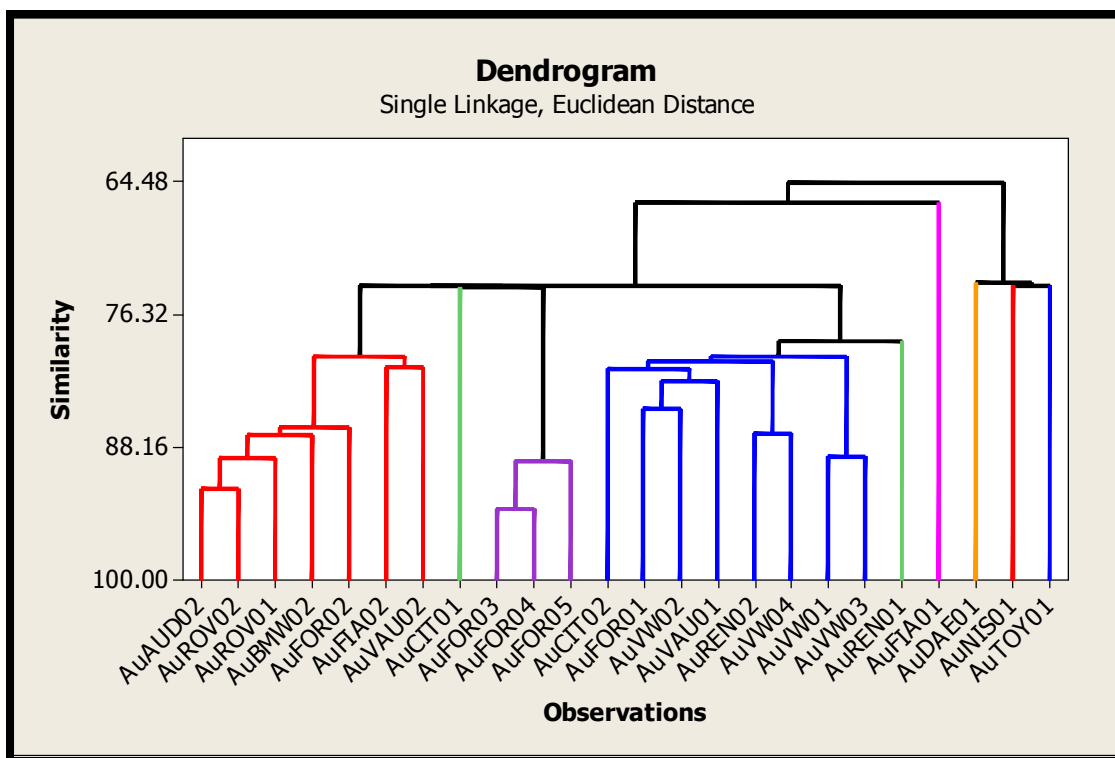


Figure 4-16 Dendrogram of groups defined by an 80% similarity level using Single Linkage and Euclidean Distance

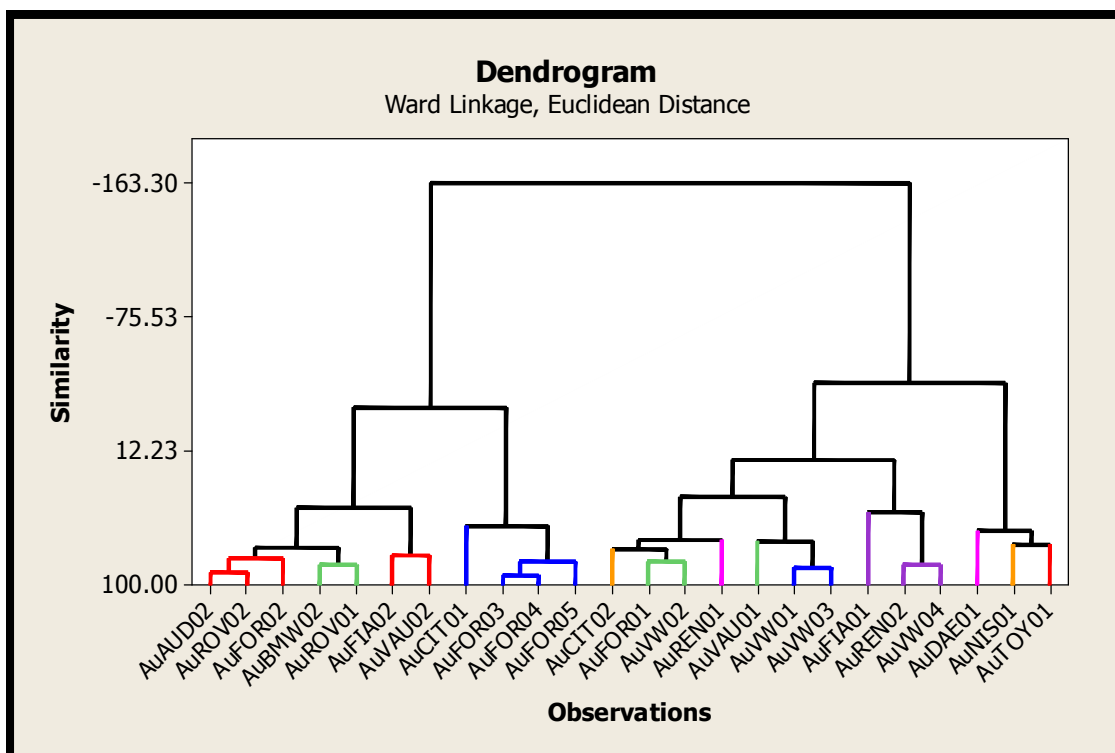


Figure 4-17 Dendrogram of groups defined by an 80% similarity level using Ward Linkage and Euclidean Distance

This analysis shows that when a level of 80% similarity is used to define the groups, the single linkage method, which links the points by closest distance, defines three groups within the data (Figure 4-16 and Table 4-17).

Group 1	Group 2	Group 3
AuAUD02	AuFOR03	AuCIT02
AuROV02	AuFOR04	AuFOR01
AuROV01	AuFOR05	AuVW02
AuBMW02		AuVAU01
AuFOR02		AuREN02
AuFIA02		AuVW04
AuVAU02		AuVW01
		AuVW03

Table 4-17 Groups defined by Single Linkage cluster analysis

When the same similarity level is used to define groups using the Ward linkage method (Figure 4-17), which links groups based on the sum of the squared deviations, seven groups are defined (Table 4-18), but these are much smaller groups containing only two or three samples. (Both techniques define more than the stated number of groups, but the ones omitted contain one sample in each and therefore are being treated as independent points).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
AuAUD02	AuBMW02	AuFIA02	AuFOR03	AuFOR01	AuVW01	AuREN02
AuROV02	AuROV01	AuVAU02	AuFOR04	AuVW02	AuVW03	AuVW04
AuFOR02			AuFOR05			

Table 4-18 Groups defined by Ward Linkage cluster analysis

What the two cluster analysis techniques demonstrate is that this data can be interpreted in two ways. On the one hand, the data can be divided into a small number of large groups. On the other hand, the data can be split into a large number of small groups. But, with the exception of samples AuCIT02 and AuVAU01 in the single linkage group 3, the same samples are being grouped in both cases. The difference is that the Ward linkage has broken the three large groups down into seven smaller groups. The groups defined by the cluster analysis can begin to be seen in the scatter plots used to visually compare the SEM-WDS data; for example, samples AuFOR03, AuFOR04 and AuFOR05 always plot together consistently. But, because these groups are small, there is a reliance on the statistical data to define the groups accurately.

The cluster analyses based on the SEM-WDS data show that the three Asian samples AuDAE01, AuNIS01 and AuTOY01 are statistically independent of each other and the other samples. This strongly suggests that the Asian samples have a different origin to the rest of the samples.

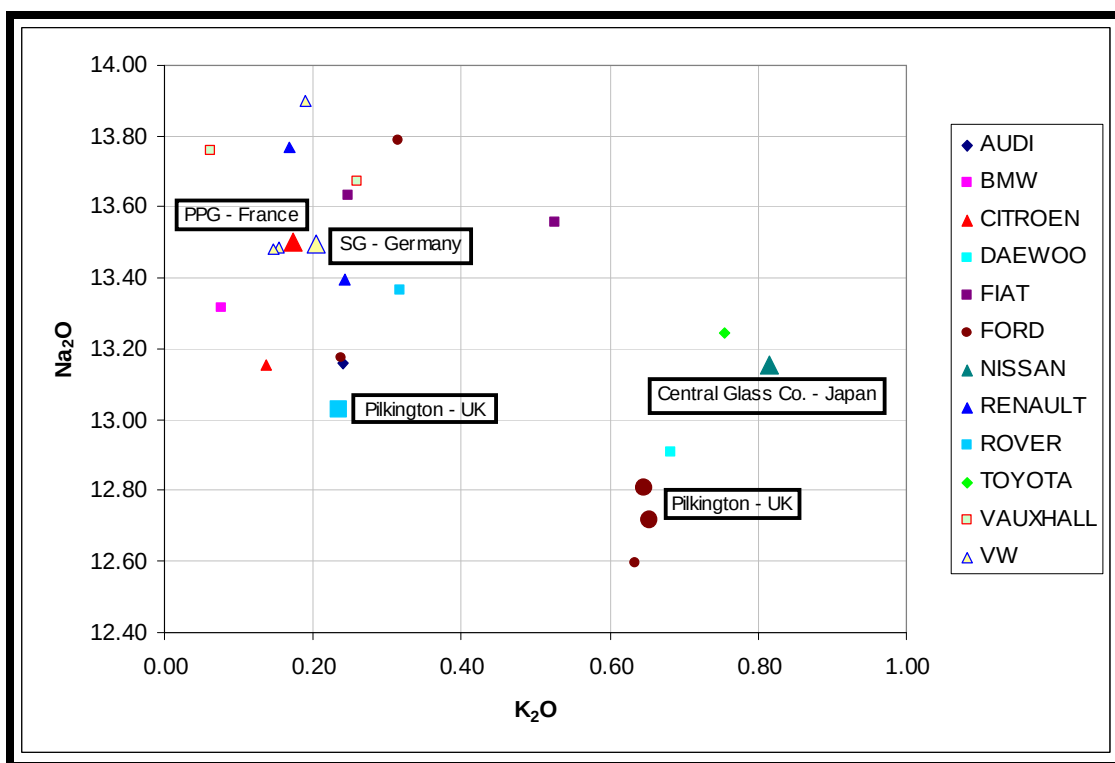


Figure 4-18 SEM-WDS graph of Na₂O vs K₂O (wt%) illustrating countries of glass manufacture where known

Figure 4-18 shows the countries of glass manufacture for six of the analysed samples; this information was recorded from the Dot number on the glass. The graph shows that AuVW04 (1988/1989 Golf) had its passenger window manufactured by Saint Gobain at their Aachen plant in Germany; AuCIT02 (date unknown Citroën AX) had its passenger window manufactured by PPG Industries in France; AuNIS01 (date unknown Nissan Sunny) had its passenger window manufactured by the Central Glass Co. in Tokyo, Japan; AuFOR04 and AuFOR05 (both date unknown, Ford Fiesta and Ford Transit) had their passenger windows manufactured by Pilkington in Birmingham, UK, and the same manufacturer made the passenger window of AuROV02 (date unknown Rover Metro). In terms of the alkali, the glass made in France and Germany appears to have a similar composition, yet the samples all made by Pilkington in the same plant have different compositions. Because the dates of the samples for which we

have manufacturers are unknown, it is impossible to say at this stage whether the differences in composition are due to a change in economic factors governing the raw material selection, or a change in recipe based on the auto manufacturers requirements.

4.8.3 LA-ICP-MS

The results of the trace element analysis show a similar pattern. There appears to be a large variation between the samples. Three of the Ford samples (AuFOR03, AuFOR04, and AuFOR05) consistently group together but there are almost always other samples in the vicinity. Therefore, it would be difficult to determine which automotive manufacturer had produced the vehicle based solely on the glass composition of an unknown sample. The trace element analyses are showing some groups forming amongst the samples, but these are again quite varied. Figure 4-19 and Figure 4-20 reflect the levels of colourants in the glass and are indicative of the potential ore sources from which the colourants came. In both graphs all the Ford samples appear to plot together, while the Toyota sample and one of the Citroën samples are distinct outliers. The plot of Nd against Fe (Figure 4-21) appears to show three groups forming with one outlying sample, while Figure 4-22 shows two groups forming with the Daewoo sample as the obvious outlier.

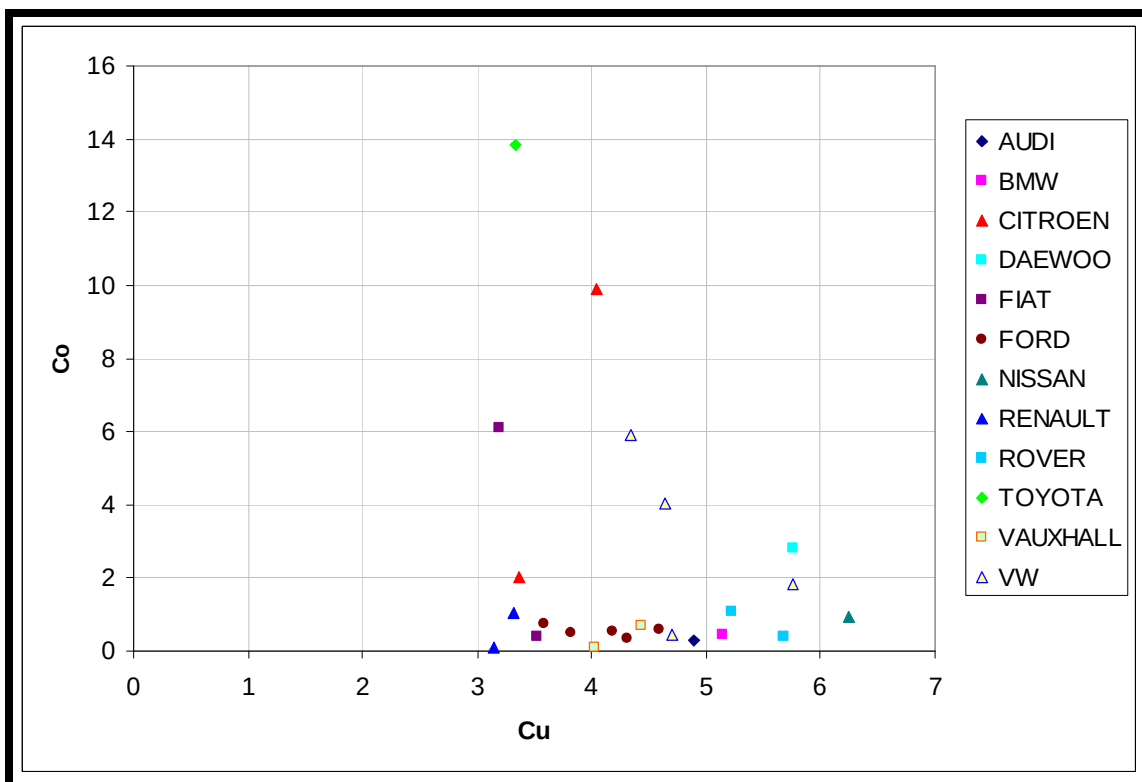


Figure 4-19 LA-ICP-MS graph of Co against Cu (ppm)

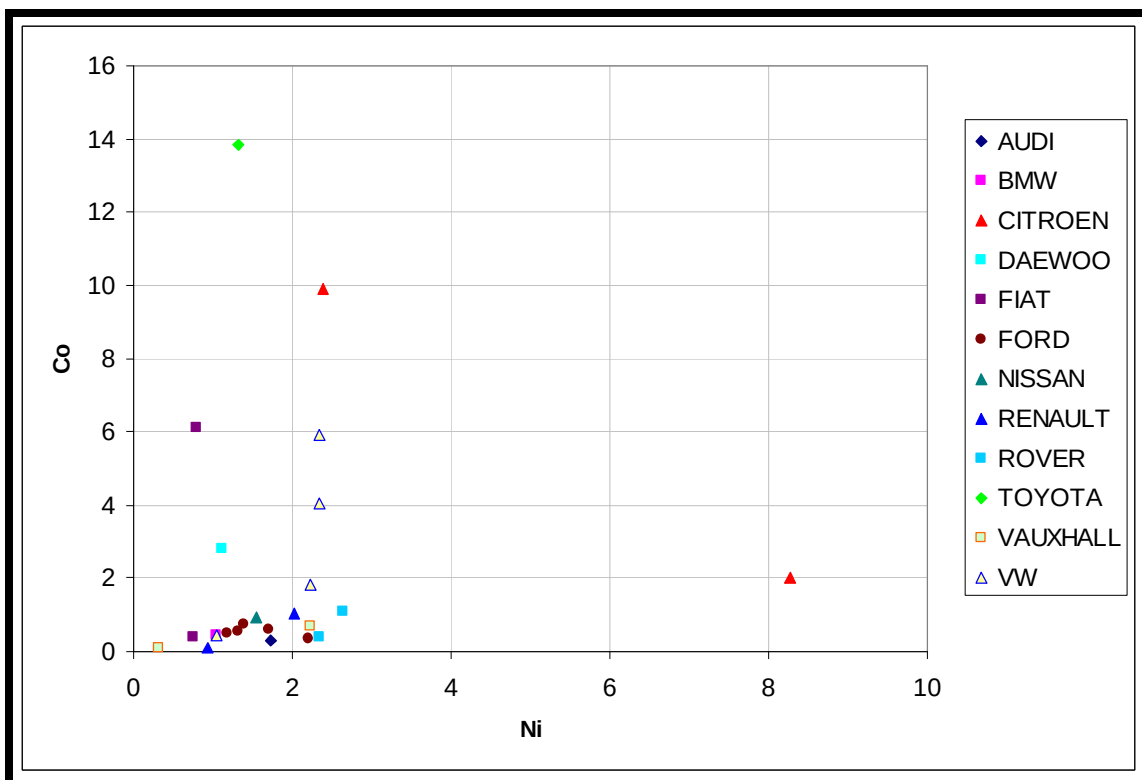


Figure 4-20 LA-ICP-MS graph of Co against Ni (ppm)

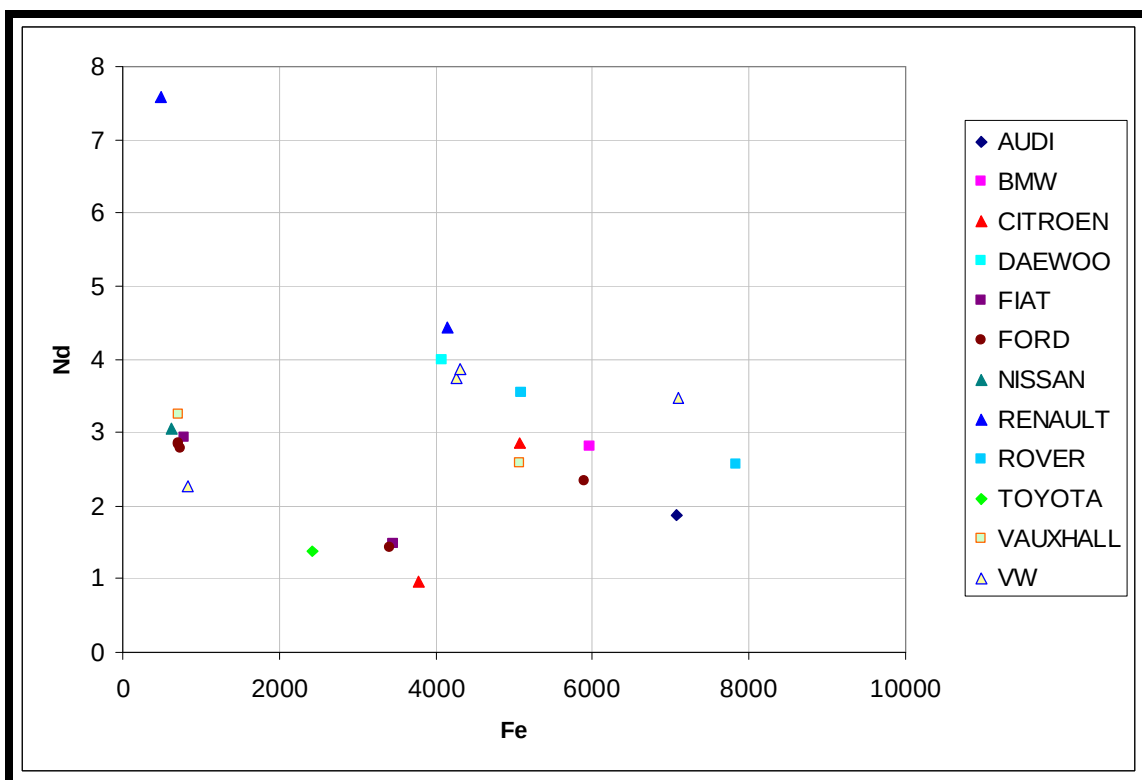


Figure 4-21 LA-ICP-MS graph of Nd against Fe (ppm)

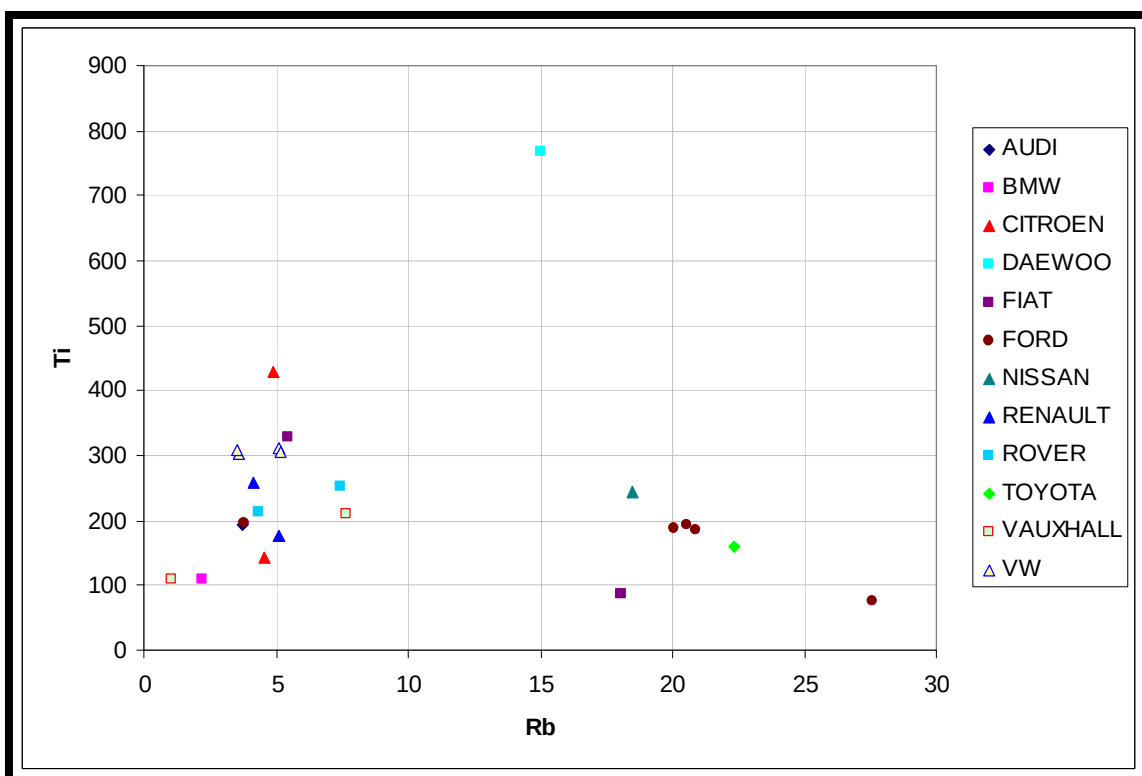


Figure 4-22 LA-ICP-MS graph of Ti against Rb (ppm)

In some cases there is a direct correlation between the elements for example, La against Ce (Figure 4-23), La against Nd (Figure 4-24), and Ce against Nd (Figure 4-25).

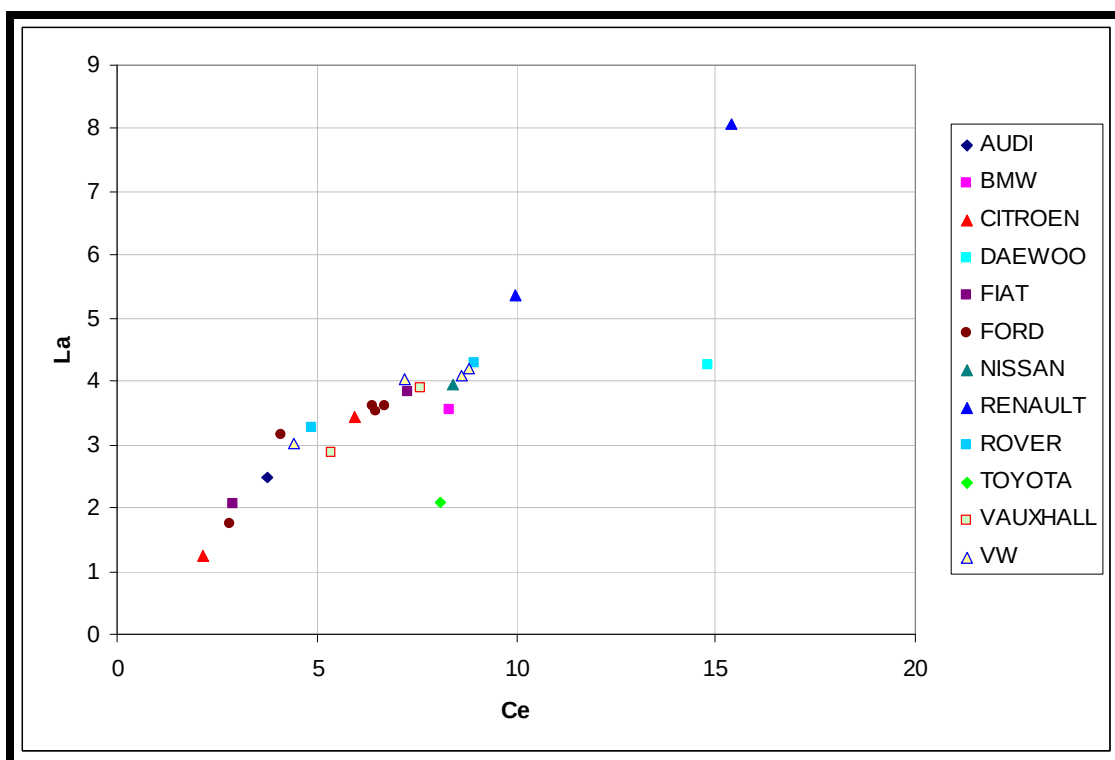


Figure 4-23 LA-ICP-MS graph showing correlation between La and Ce (ppm)

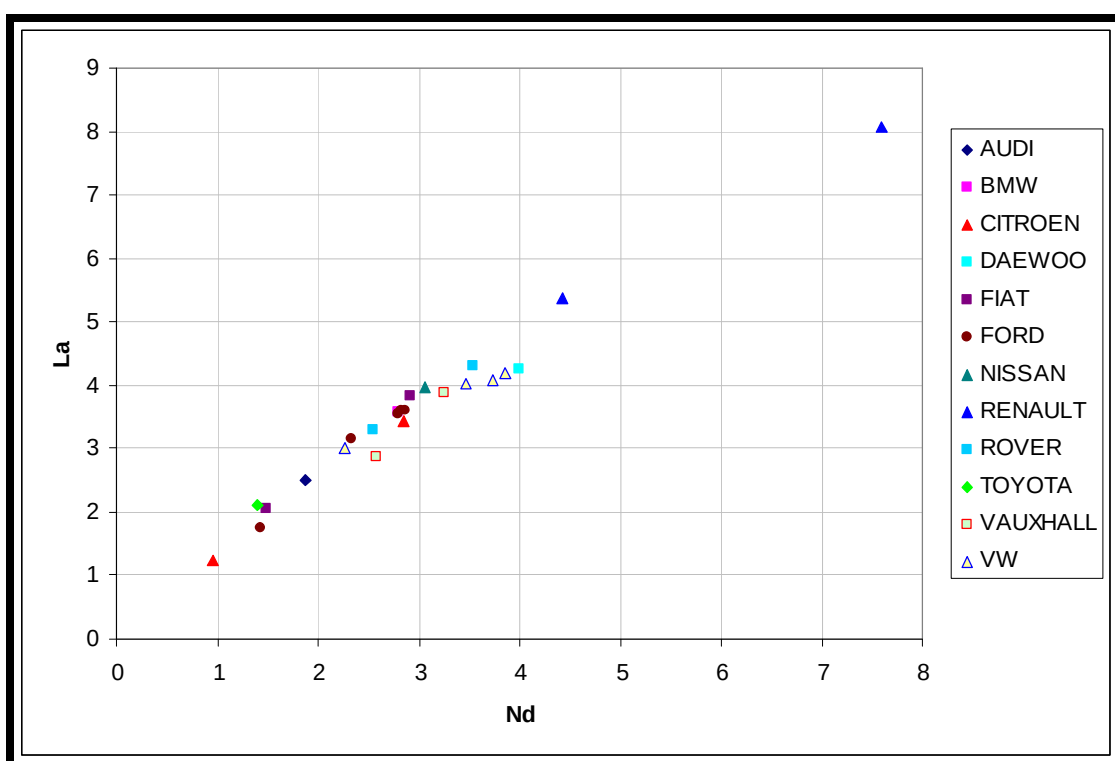


Figure 4-24 LA-ICP-MS graph showing correlation between La and Nd (ppm)

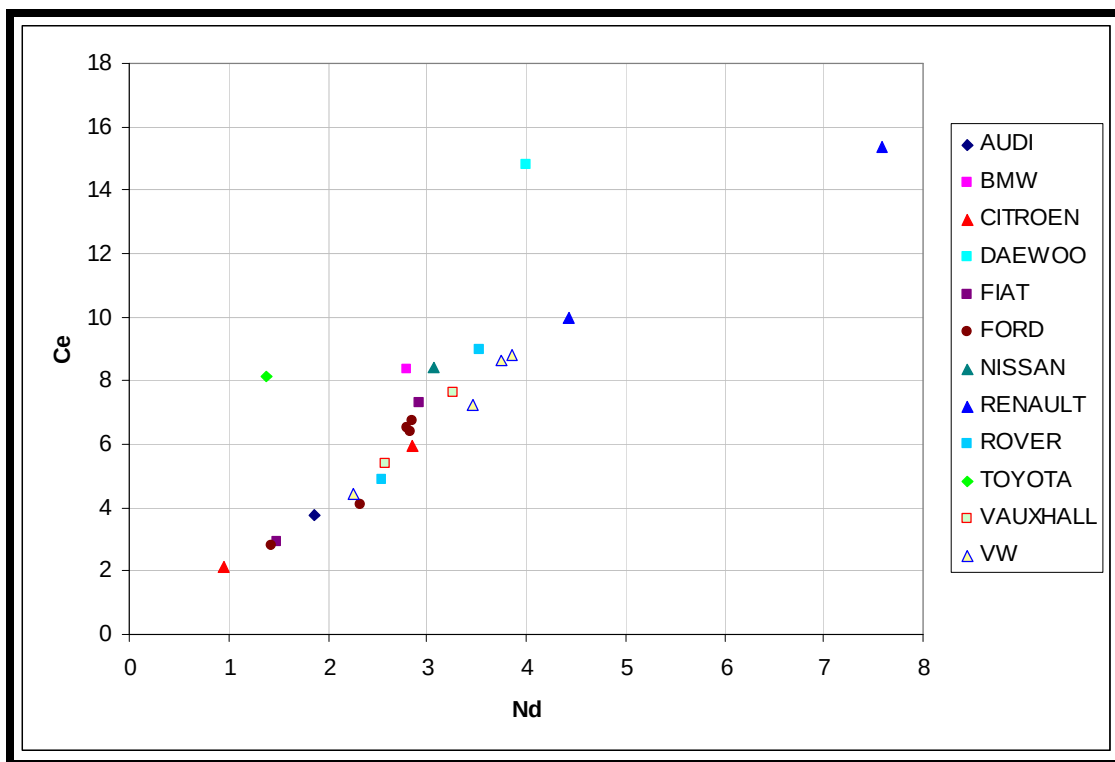


Figure 4-25 LA-ICP-MS graph showing correlation between Ce and Nd (ppm)

As with the minor elements, the large spread of the data indicates that the raw materials used in the manufacture of the windows have come from very varied sources. Also, glass from the same manufacturer in different makes of vehicle has different raw material signatures. This can be seen in Figure 4-26, where the Fords from Pilkington, UK and the Rover from Pilkington UK, which according to the Dot No. details were made at the same facility, have distinctly different signatures. In terms of the Rb in the graph in Figure 4-26 it appears that the samples from Europe, with the exception of four of the Fords and one Fiat sample, group together. As the plant location data is unavailable for AuFIA01, AuFOR01 and AuFOR03, it is hard to draw conclusions as to what this division means.

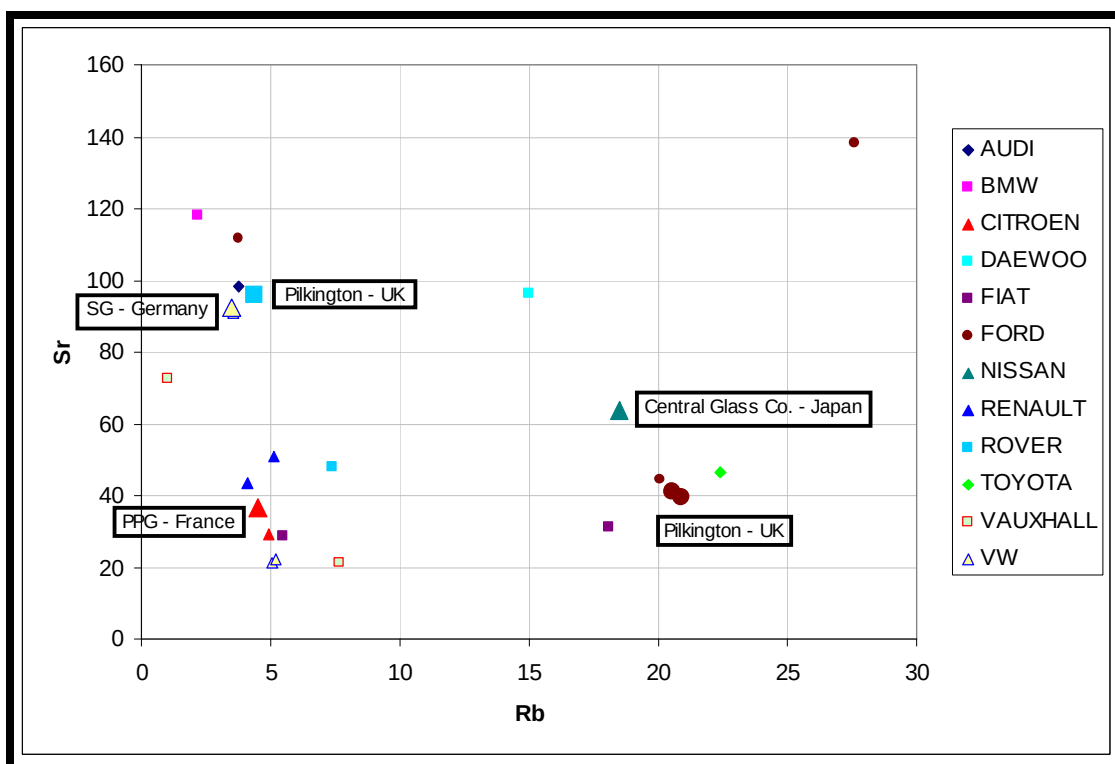


Figure 4-26 LA-ICP-MS graph showing the manufacturing location of 6 of the glass samples

PCA was also performed on the trace elemental data, again, in order to determine which variables had the most influence over the data and therefore should form the basis of the cluster analyses. The results of the PCA analysis on the LA-ICP-MS data shows that the data set can be characterised by three principal components. These three PCs account for 99.8% of the data. But this is when the PCA includes Ca, Al, and Fe, which are overpowering the trace elements. In this case they must be removed from the analysis and the PCA programme run again. In the second attempt at PCA without the dominant elements of Ca, Al and Fe in the analysis, 2 principal components account for 88.2% of the data. Although adding more principal components will account for more of the data, the contribution of these other components is so small, that very little information is lost by discounting them. The elements with the most influence in terms of these components are: Ti, Mn, and Ba.

The single linkage (Figure 4-27) and ward linkage (Figure 4-28) cluster analyses of the trace elements focused around the key elements of Ti, Mn, and Ba. Both cluster analyses were again capped at the similarity level of 80%.

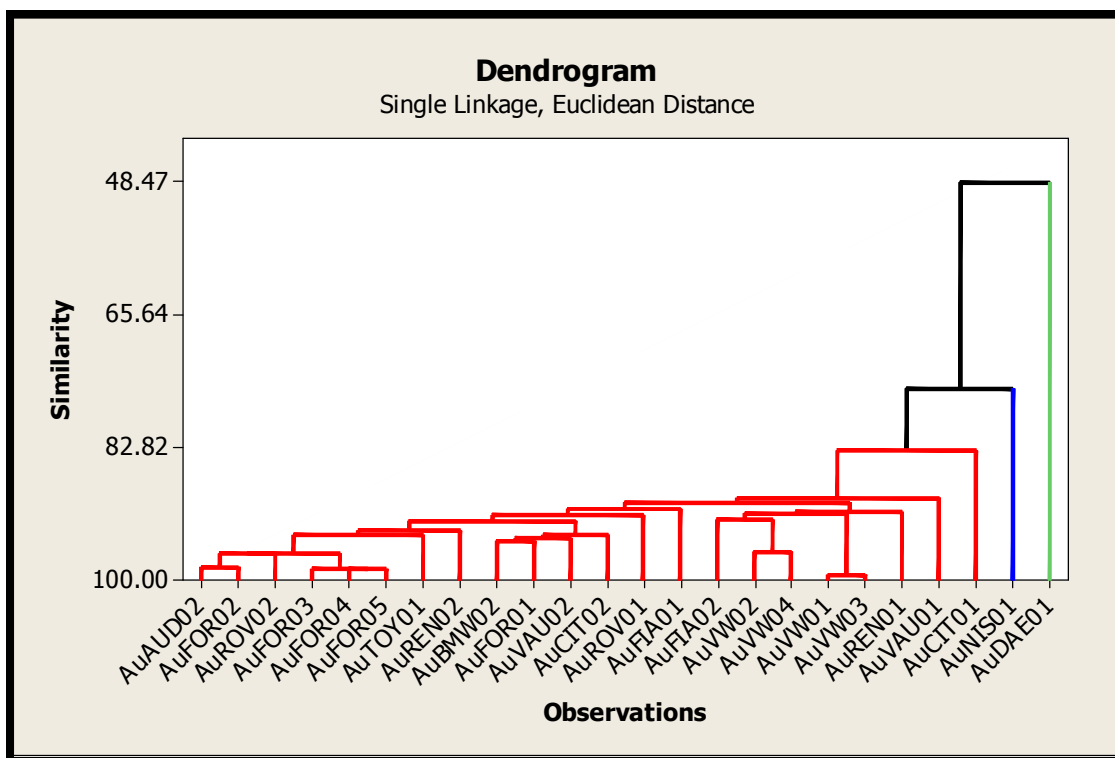


Figure 4-27 Dendrogram of groups based on Single Linkage, Euclidean Distance

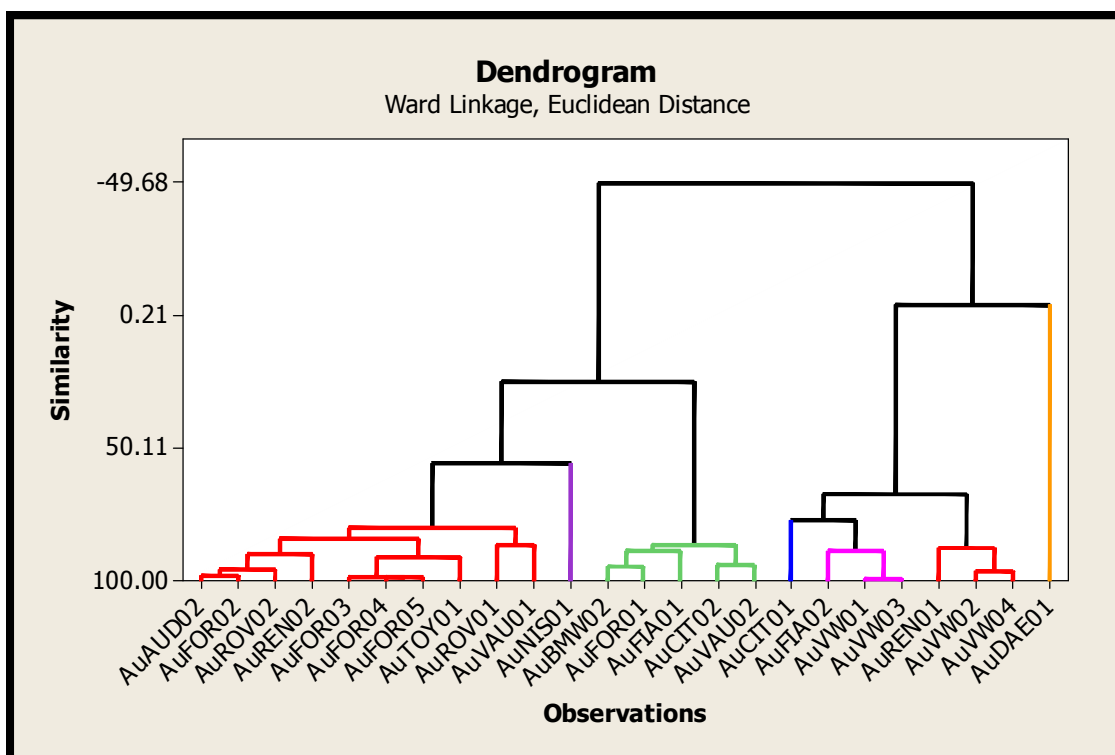


Figure 4-28 Dendrogram of groups based on Ward Linkage, Euclidean Distance

The two dendrograms show that with an 80% level of similarity, the single linkage method defines one main group (containing all the samples) with two outliers

(AuNIS01 and AuDAE01). The Ward linkage method again defines a larger number of smaller groups, in this case 4 groups (Table 4-19).

Group 1	Group 2	Group 3	Group 4
AuAUD02	AuBMW02	AuFIA02	AuREN01
AuFOR02	AuFOR01	AuVW01	AuVW02
AuROV02	AuFIA01	AuVW03	AuVW04
AuREN02	AuCIT02		
AuFOR03	AuVAU02		
AuFOR04			
AuFOR05			
AuTOY01			
AuROV01			
AuVAU01			

Table 4-19 Groups defined by Ward Linkage, Euclidean Distance with 80% similarity level

Although the groups formed by the cluster analysis of the trace elements and those of the major/minor element analysis do vary from each other, this just highlights the complex nature of the data. The cluster diagram of the trace elements (Figure 4-28) shows that four sub-groups can also be highlighted where the samples group with a similarity of 96% or better (Table 4-20).

Group 1	Group 2	Group 3	Group 4
AuAUD02	AuFOR03	AuVW01	AuVW02
AuFOR02	AuFOR04	AuVW03	AuVW04
AuROV02	AuFOR05		

Table 4-20 Groups defined by Ward Linkage, Euclidean Distance with a 96% similarity level

According to the trace element cluster analysis the samples in group 1 and 2 (Table 4-20) are part of the same group, but would appear in separate groups if a similarity level of 96% was set. If the results of the LA-ICP-MS cluster analysis is compared with the SEM-WDS cluster analysis, then it can be seen that certain samples appear to consistently group, and can therefore be said that these samples form true groups (Table 4-21).

Group 1	Group 2	Group 3
AuAUD02	AuFOR03	AuVW01
AuFOR02	AuFOR04	AuVW03
AuROV02	AuFOR05	

Table 4-21 True groups defined by the comparison of the major/minor and trace element cluster analyses

These three groups (Table 4-21) can be compared on the scatter plots of the elements to see how and where the samples relate to each other. Although the results of the statistical analysis has identified three groups and these groups do not contain more than three samples each, it is encouraging to note that two of the groups comprise of two specific makes of car. Group 2 is made up of three of the five Fords, and group 3 is made up of two of the four VWs. Group 1 is made up of three brands of car Audi, Ford and Rover. AuROV02 is known to have been produced at the Birmingham Pilkington plant, and the AuFOR04 and AuFOR05 are both also made in the same plant. The proximity statistically of AuFOR02 to AuROV02 and the fact that AuROV02 and both AuFOR04 and AuFOR05 are all Pilkington glass suggests that it is also probable that AuFOR01 was also a Pilkington glass. Although the LA-ICP-MS analyses have indicated an even greater spread in the data than the SEM-WDS analyses, the data has shown different groups forming. In some cases, for example, the Asian samples, do not group together in terms of the trace elements, which further complicates the interpretation of the data.

4.8.4 Isotopes

The isotope analysis compliments the data from the trace element analysis and shows that the samples have a very large spread across the Sr and Nd. Again, the three samples of Ford appear to group, and some of the other brands are showing similar isotopic compositions to each other. The glasses can also be characterised based on the Sr and Nd isotopic compositions (Figure 4-29). Although the data has a large spread, there is a split occurring, visually there are two main groups, those with lower Sr ratios, between 0.705694 and 0.706246, and those with higher Sr ratios (>0.710151). The higher Sr group could potentially be further split, the samples with Sr between 0.710151 and 0.712420, and those with Sr ratios above 0.713897. There is less of a spread amongst the Nd signatures, with one main group, and two outlying samples. The majority of the Nd signatures lie within the range 0.511869 – 0.512175; there are two exceptions AuTOY01 (0.512296) and AuBMW02 (0.511241). Sample AuBMW02 has a noticeably different Nd isotopic composition to the other samples.

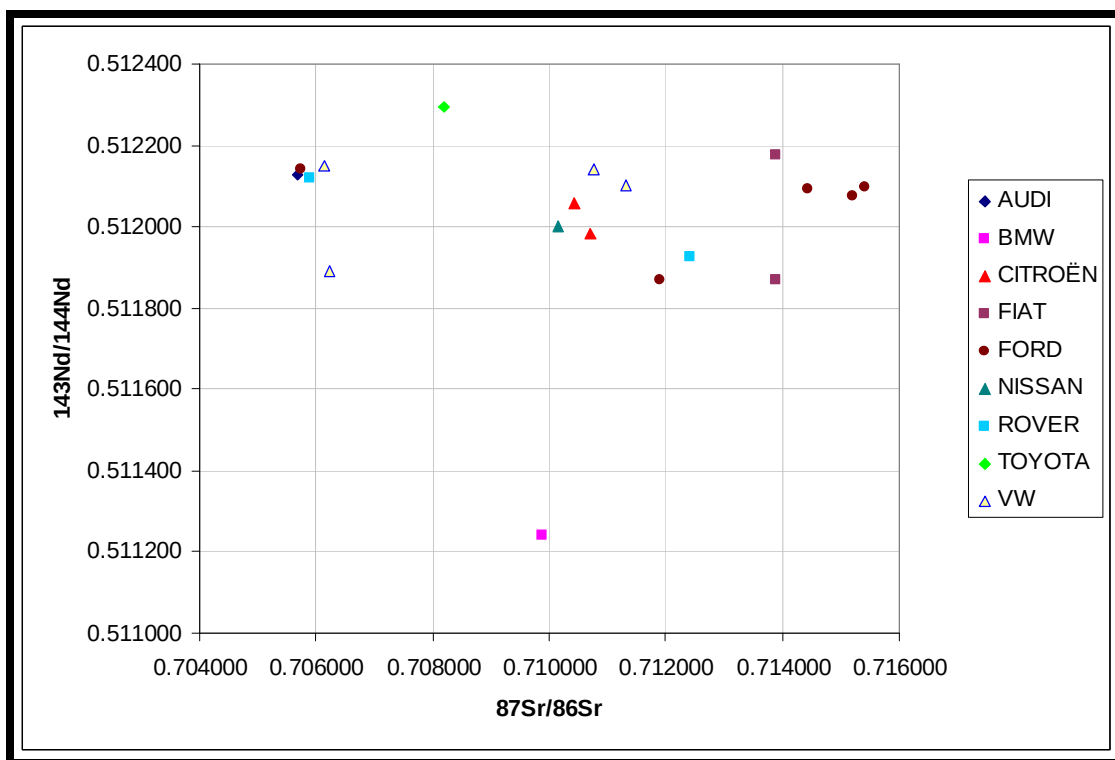


Figure 4-29 Nd and Sr isotopes

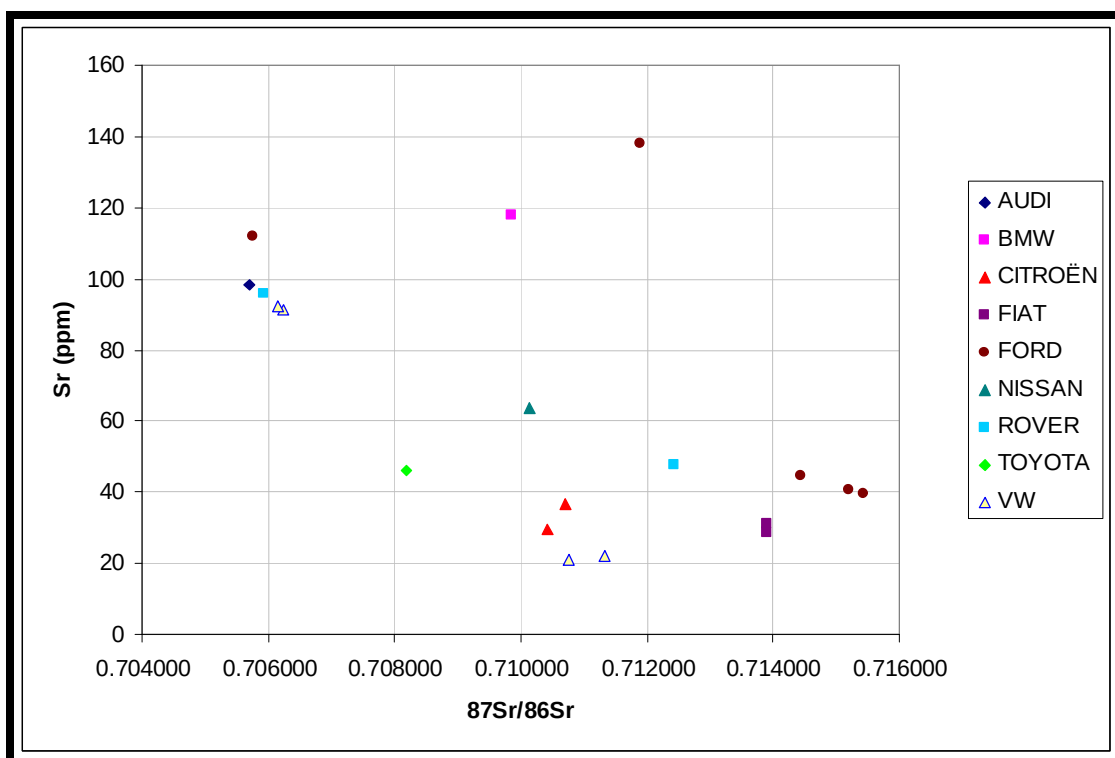


Figure 4-30 Elemental Sr against Sr isotopes

A further interrogation of the Sr data (Figure 4-30), by plotting the elemental Sr values (ppm) against the $^{87}\text{Sr}/^{86}\text{Sr}$ values shows that the two main Sr groups can be

further defined by their elemental composition (Table 4-22). The lower $^{87}\text{Sr}/^{86}\text{Sr}$ group has higher elemental Sr (91-112ppm), whereas, for the most part, the higher $^{87}\text{Sr}/^{86}\text{Sr}$ group has lower elemental Sr (21-64ppm). With this comparison, it can be seen that certain brands of car are beginning to group together, for example, the two Fiats, the two Citroëns, two pairs of VWs (although these two pairs themselves are quite distinct from each other), and three of the five Fords. AuVW01 and AuVW03, which have the lower Sr concentrations at around 20 ppm, are both from VW Sharans.

Group 1	Group 2	Outliers
AuFOR02	AuNIS01	AuTOY01
AuAUD02	AuCIT01	AuBMW02
AuROV02	AuCIT02	AuFOR01
AuVW02	AuVW01	
AuVW04	AuVW03	
	AuROV01	
	AuFIA01	
	AuFIA02	
	AuFOR03	
	AuFOR04	
	AuFOR05	

Table 4-22 Visual groups based on isotopic analysis

The Nd isotopes are indicative of the silica source used in the glass, while the Sr isotopes relate to the lime component. The results of the isotope analysis show that most of the samples of auto glass are using similar sources of silica for their glass. The major exception to this is the BMW sample; it is also possible that the sample of Toyota glass also has a different silica source to the other samples. The higher Nd ratios are indicative of ‘older’ geological sands being used in the manufacture of the glass (Brems 2010 pers. comm.).

The high Sr ratios again suggest the influence of an ‘old’ source of Sr (Brems 2010 pers. comm.). If impure sands are being used in the manufacture of the glass this may indicate an older mineral content to the sand (Brems 2010 pers. comm.). Alternatively, the Sr signature could be indicative of the lime bearing component of the glass.

4.9 Discussion

The analyses of the refractive indices (RIs) of the samples of automotive glass showed that the sensitivity of the GRIM 3 allowed the differentiation of all the samples at a 95% confidence interval. This means that all the samples were defined as coming from separate panes of glass. If a control sample of glass were introduced, the forensic technique of RI analysis would be able to distinguish which if any of the samples came from the same glass as the control sample. The use of RI is also used to place unknown fragments of glass into arbitrary categories. In this case, the RI analyses placed three of the samples into the windscreen glass category, while the remainder were all within the limits for architectural glass. RI could provide no further information about the samples; therefore, in forensic cases where there is no control sample, this technique is of limited use. The results of the RI show that the standard technique used works in terms of the question being asked. For example, the question asked of forensic glass scientists is, do the two samples (questioned and control) match; in other words are they from the same piece of glass? The precision offered by the GRIM 3 in terms of RI analysis will differentiate between all of the modern auto glass samples used in this study. In cases where the RI alone does not achieve this then elemental analysis of the glass is used, if the two samples are indistinguishable with both techniques then they are the same. The techniques, used as standard in the analysis of archaeological glass, are available for use forensically but will not add anything to an attempt to answer the question of whether two samples match. What the application of the 'archaeological' techniques has illustrated is that more information can be gained from the samples by changing the question being asked. For example, if questions relating to the composition and provenance of the data are asked, then the elemental techniques contribute a lot of information. In a situation where an unknown glass has been discovered at a crime scene, i.e. glass recovered from a hit and run incident, and there is a lack of a suspect sample, then the determination of the RI will impart little further information. This does not mean that the glass is useless as evidence; further information can be gained from the study of the elemental and isotopic composition. The application of an archaeological interpretation of the glass can yield information as to the potential origin of the sample.

The results of the elemental and the isotopic analysis show that the glass from the car windows can begin to be grouped based on the composition. The compositional and statistical data shows that there are eight samples which are beginning to consistently group; Group 1 - AuFOR02, AuROV02 and AuAUD02; Group 2 – AuFOR03, AuFOR04 and AuFOR05 and Group 3 - AuVW01 and AuVW03 (Table 4-21). In terms of the major/minor elemental analyses the three samples of ‘Asian’ glass were consistently grouped as outliers, implying a distinctly different raw material source (Figure 4-16 and Figure 4-17). Due to the small nature of the data set, it is unclear exactly what these groups mean. Based on groups 2 and 3 it would be easy (and convenient) to say that the techniques used demonstrate that different makes of car can be determined based on the composition of the window glass. Group 1 shows that this is clearly not the case. The relationship between car manufacturers and glass manufacturers is complex; what the data does begin to show is that grouping is occurring on a global scale. For example, the raw materials used in the manufacture of the Asian glass are distinct from the other glass in terms of the major and minor elements. The data was also plotted based on whether the samples were taken from side windows or windscreens and this did not result in consistent groups. An attempt has also been made to determine whether the known country of origin of some of the samples aids the formation of groups. Again, nothing conclusive could be drawn from this approach; the sample of German origin grouped with one of the UK samples and the only two of the UK samples consistently grouped despite the fact that all three samples of UK glass supposedly came from the same plant.

In terms of the major elements, there is very little variation between the samples; this is because of the standardised recipes used. At look at the minor elements present in the samples begins to show some variation, in particular with K_2O , Al_2O_3 , and FeO . Within this data, certain makes of vehicle are beginning to group together, for example, some of the VWs (AuVW01 and AuVW03), and some of the Fords (AuFOR03, AuFOR04, and AuFOR05). A study of the trace elements in the samples shows even greater variation in the glass. In some cases, correlations can be seen between some of the elements, especially amongst the rare earth elements. By plotting other trace elements, such as Sr against Rb (Figure 4-26), it is possible to see groups forming, and

again, some samples such as AuFOR03, AuFOR04 and AuFOR05, are grouping together consistently.

The isotopic data confirms the results of the trace elements, indicating a large spread in the data. The spread is so large, not only between brands but also in some cases between the same brand, that these provenancing techniques can be used to determine the make of a car or the glass manufacturer based on the composition of an unknown piece of glass. In order for this process to work a large database of information would need to be constructed and maintained. If the data is only being used to answer the question of whether two samples of glass match, then the cost and time involved in obtaining the isotopic results is not worth the investment, because the trace elemental analysis will show a similar pattern. If, however, a database were being constructed, or information as to the raw materials being used by the glass manufacturers were required then the isotopic analysis could be extremely useful.

A commercial glass composition represents the compromise between four sets of requirements:

- The end use demands
- The glass preparation process i.e. melting, fining, homogenising
- The working processes i.e. forming and shaping the glass
- The economic and market demands (Tooley 1984a)

It is also apparent that there are enormous numbers of potential glass compositions (Lyle & Tooley 1984). Although there are a large number of different glass compositions available, it is likely that the range for a specific market could be quite small. In terms of the major/minor elements in glass, there is small variation in auto glass ‘recipes’ but in terms of the trace elements it has been shown that the variation between the glasses is quite large. This relates directly to requirements outlined above, for example, the car manufacturer (customer) defines what properties the glass must have, this will include any special coatings, heat resistant properties or auto ‘trimmings’ such as heating bars, or aerials etc. The glass manufacturers then make the glass to the customer’s specifications, but adding their own signature along the way i.e. the glass manufacturer chooses/sources the raw materials, shapes the glass and adds the final touches to the window. The glass manufacturer’s choices are driven by economic and market choices in terms of the raw materials used and the production processes employed.

In order to design an appropriate glass the manufacturer will provide an approximate chemical composition that is close to the desired outcome, a process of experimental melts will then be made and tested and the 'recipe' modified until the correct composition is achieved (Lyle & Tooley 1984). The elemental analyses of the automotive glass samples may be showing the patterns of selective manufacture, i.e. the 'recipes' chosen by specific manufacturers to satisfy particular clients. This may explain why the Pilkington Rover and Ford samples differ in composition despite being made in the same plant.

The major raw materials used for glass making can be considered in three classes (Tooley 1984a). The first are materials that have to be mined or quarried, they are often milled and beneficiated after extraction to make them suitable for the industry. Examples of this type of material would be sand, limestone or dolomite. These materials can then be further sub-divided into those such as sand and limestone, which consist of a large amount of the major constituent and a small amount of accessory minerals; and those such as feldspathic materials, which are not found singly in a pure state (Tooley 1984a). The second class of materials are those which are chemically manufactured, such as synthetic soda. While the third group are 'by-product' materials such as cullet and beneficiated blast furnace slags (Tooley 1984a). All of the above classes of material are routinely used in the production of modern commercial glasses to varying extents. For example, container glass can contain more cullet because the physical properties of the glass are not necessarily negatively affected, whereas auto glass, which has very specific technical and physical requirements, would use less cullet as the composition of the scrap glass is harder to control.

In addition to the different classes of raw material available, the purity and quality of different sources of the same raw material will vary and this is where the economic issue arises. For example, is it cheaper to use lower quality raw materials and pay for the beneficiation, or is it cheaper to import purer raw materials? The spread of the samples in the results is illustrating the different choices made by the glass manufacturers in terms of the raw materials used. For example, the MgO contents of the samples (between 3.57 and 5.01 wt%) are indicative of the use of dolomitic limestone in the glass batch (Ingram 2010 pers. comm.), the MgO is specifically added the glass melt in order to help prevent devitrification of the glass ("B.G.S" 2006).

The more ‘impurities’ a raw material contains, the more work is needed in order to incorporate the material into the glass. For example, if the sand used contains iron, then the cost of beneficiation can be high (Akpokodje & Etu-Efeotor 1987). On the other hand, if the ‘impurities’ referred to are Al_2O_3 and CaO (in terms of the sand it is not pure silica as it contains these other oxides) then the sand does not need to be purified, but the batch calculations need to be adjusted to take account of the additional components. Certain oxides can result from the purification of blast furnace slags, including silica, lime and magnesia (Tooley 1984a). The use of by-product materials, although purified will complicate further the signature of the raw materials. In terms of the results of the car glass analyses, the older samples may well have incorporated oxides derived from metal slags, although this is less likely with the more modern samples because of the standards required in the industry and the specific properties required by customers.

The Nd isotope analysis has shown that the sand sources being used by the glass manufacturers for the purposes of making auto glass are coming from ‘older’ sand deposits, usually found in Western Europe. The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios for these rocks are usually between 0.512023 and 0.512228 (Brems 2010 pers. comm.). The Nd in the sand comes from the non-quartz, mineral content of the deposit used (Degryse & Schneider 2008). In theory by comparing the Nd isotope content of the glass with that of the sand raw material, specific sources can be eliminated as the origin of the silica used. The silica used in the glass industry, commonly called glass sand, is essentially comprised of quartz grains, the best sources of glass sand are very pure and contain 99.6-99.8% SiO_2 , with $\text{Al}_2\text{O}_3 < 0.3\%$ and iron consistently below 0.025% (Tooley 1984a). Despite this, the samples of glass analysed were found to contain up to 2% Al_2O_3 and up to 0.77% FeO. This suggests that the impurities within the raw materials are not as controlled as first thought. The glass for car windows is made by a continuous glass making process, and therefore, heterogeneity in the sand causes problems in terms of controlling the chemical composition of the batch (Highley). This said, as mentioned earlier, other ‘beneficial’ elements may be present in the sand for example, lime, and for economic reasons it may be better to use sand that contains quantities of feldspar (Highley). i.e. it may be economically better to acquire and use a sand containing other components and then adjust the glass recipe, than spending large amounts of money importing pure raw

materials or purifying existing impure ones. In terms of the samples made in the UK, assuming that the sand used in the manufacture of these windows originally came from the UK, then there are only two possible sources of flat glass sand (Figure 4-31).

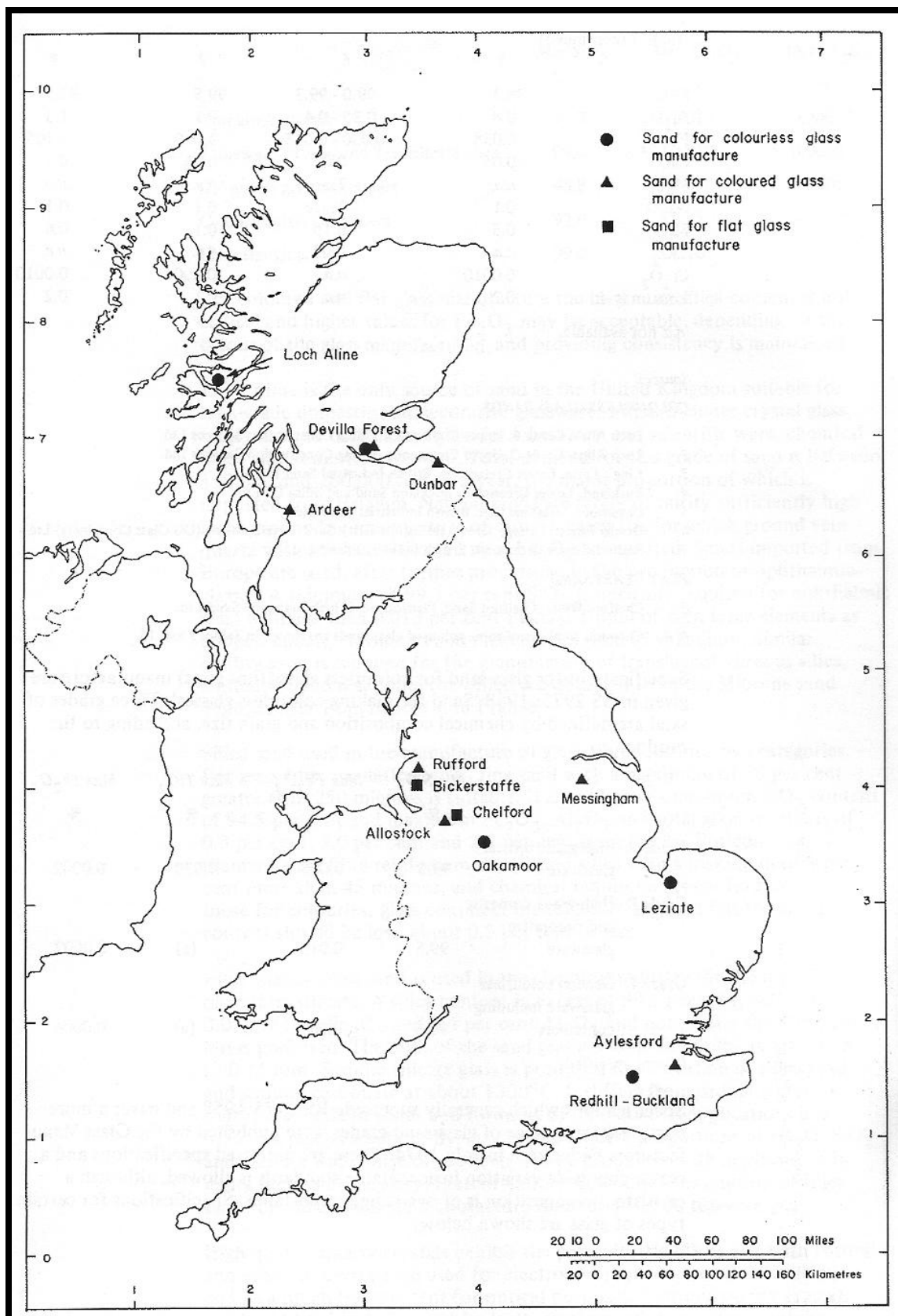


Figure 4-31 Sources of UK glass making sand 1976 (Highley: 10)

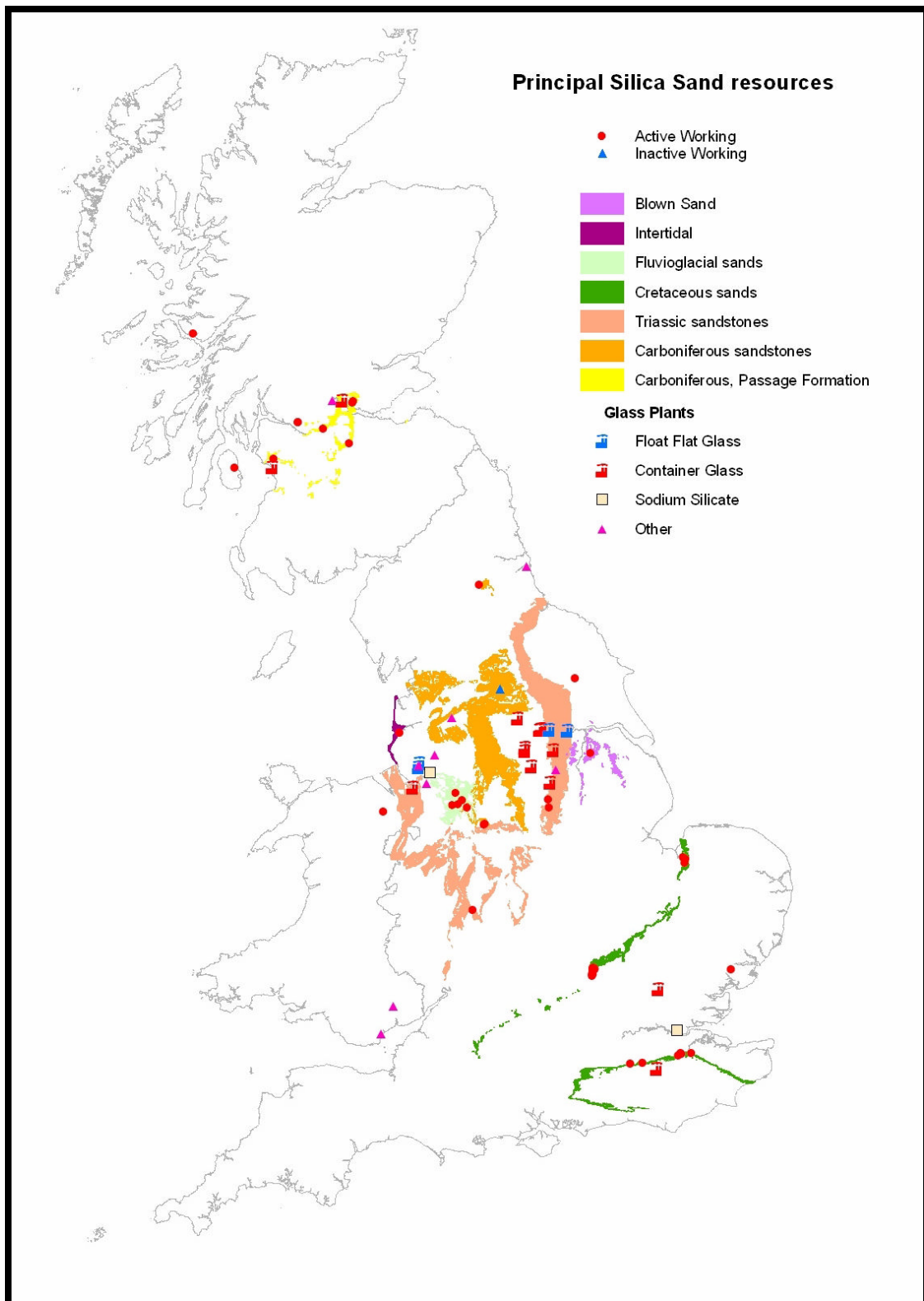


Figure 4-32 Current UK silica resources (http://www.samsa.org.uk/downloads/silica_uk.pdf)

A comparison of the two maps (Figure 4-31 and Figure 4-32) indicates that during the 1970s there were two principle locations for sourcing sand suitable for the

flat glass industry (and therefore car window manufacture) in the UK. Today, there are three sites that produce flat glass in the UK and all are within relatively close proximity to the quarries highlighted in the 1970s. The quarries in Figure 4-31 appear to lie in the region around the Triassic sandstones and Fluvioglacial sands (Figure 4-32); these deposits in the UK characteristically have a $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of around 0.512074 (Degryse 2010 pers. comm.). Samples AuFOR03, AuFOR04, AuFOR05 and AuCIT01 are all between 0.512059 and 0.512097; samples AuFOR04 and AuFOR05 are both manufactured by Pilkington in their Birmingham, UK plant.

“United Kingdom resources of sand and sandstone are extremely large but only a very small proportion possess the desired physical and chemical properties to be classed as silica sand, consequently most sands need to be upgraded before use. Theoretically at least it would be possible to produce acceptable grades of silica sand from many sands and sandstones in Britain but the viability of upgrading inferior quality sand will depend ultimately on whether it can compete in price with existing sources of supply” (Highley: 18-19).

If it is assumed that a relatively pure source of silica sand is used for the manufacture of auto glass, then it will contain only minor amounts of lime and alumina. In this case, the other raw materials of the glass must be considered in order to explain the Sr isotopic signatures. Figure 4-30 shows that a comparison of the Sr content against the Sr isotopes splits the data into two groups, those with a high $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and lower Sr content and those with a low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and higher Sr content. The Sr content in the car glass has most likely been incorporated from the limestone, dolomite and feldspar materials used to provide CaO , MgO , and Al_2O_3 . The most probable source of the Sr for sample AuTOY01 which has an $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7082 and a Sr content of 46ppm is limestone (Degryse 2010 pers. comm.); this is because the Sr isotopic ratio is below that of modern seawater (Veizer et al. 1999) and therefore reflects the composition of the seawater at the time the limestone was deposited (Brems 2010 pers. comm.). The other samples which have the noticeably higher and lower Sr ratios are most likely to have come from feldspar sources; the sources having different origins hence the divergence in the ratio signature (Degryse 2010 pers. comm.). Due to the likelihood of the glass recipe also incorporating limestone and dolomite as well as feldspar it is probable that the feldspar signatures represent a mix of potentially all three

sources, further complicating the picture. The lime component of the glass can come from limestone, but also from dolomite and blast furnace slag. In order to be able to attribute the Sr signature in the glass to one of these sources, the composition and signature of the source would need to be known.

What the results do highlight is that in order to begin to assign the glass samples to specific manufacturers and therefore sources of raw material, certain things need to be known in advance. Firstly, if the glass comes from a known vehicle, then the information from the window stamp is essential, in particular, the Dot No. which specifies the manufacturer and the plant in which the glass was made. Once this crucial piece of information has been ascertained then it is possible to begin to 'catalogue' the compositions of different vehicle windows relating to specific plants in specific years. In this way a database of windows relating to manufacturers can be created. A combination of techniques to analyse the samples will result in the ability to determine the nature of the raw materials used, and this can be compared to the database of the manufacturers and the locations of specific plants. Therefore, information will be available as to whether manufacturers were using local raw materials or importing them at a given time.

4.10 Limitations

The results of the analyses of the samples of auto glass indicate that the raw material signature of the samples can be detected. The different makes of car do not always group together, this can be for two reasons; the recipe for the glass may vary between models of car, or it may vary between dates. Similarly, in cases when a specific glass manufacturer is known to have produced the glass for two different makes of vehicle, the composition can again vary. This may be because the customer (the auto manufacturer) requested a specific property for the glass which may have varied the raw material used; or more likely, the dates of the vehicles are different and the economic situation dictated where the raw materials chosen have come from. The fact that some of the samples are beginning to group together is encouraging. This shows that the archaeological provenancing approach clearly works even for modern glass where the manufacturing techniques and overall recipes used are tightly controlled.

This pilot study has shown the potential of using provenancing techniques on modern vehicle glass. What it has also illustrated is the need for more data. At this stage it is unclear whether the results are showing differences between makes/models of vehicle or between glass manufacturers or even between dates. For example, a larger database would have the potential to show whether Pilkington glass from a particular year all grouped together irrespective of make/model. Alternatively, a larger database could show whether specific models of car are grouping together irrespective of year. With the present research the samples appear to group best when compared by manufacturer rather than by date or window.

By comparing the analyses of the samples with the data collected from the car survey, an understanding of the complex nature of the automotive glass industry can begin to be created. For example, according to the DA survey, almost all Renaults surveyed had windscreens manufactured by Saint Gobain. In particular, all bar one of the Clio models had Saint Gobain windscreens. Of the glass analysed two samples were from Renault windscreens of which one was a Clio. The Renault Clio was from 1999 and the other Renault (of unknown model) was licensed 1992/1993. These two samples, for the most part, group relatively well together in terms of the trace elements. When plotted on a graph of Sr against Rb (Figure 4-26) these two samples group with the PPG – France manufactured Citroën. Therefore, it may be possible that these two samples were manufactured by Saint Gobain in their Thourotte plant in France. They do not group with the known Saint Gobain manufactured VW Golf side window, because this latter window was manufactured in Germany. Similarly, the three samples manufactured by Pilkington in their Birmingham, UK plant do not all group together even though they are all side windows. The recipe used on the Rover sample is clearly a different composition of glass to the Ford samples. Unfortunately these samples are all of unknown date and so it is impossible to tell whether the date may in this case have been an influencing factor on the composition.

What this research does show is that a complete database of glass samples would be a very powerful tool for forensic analysis. With a large enough sample set, the patterns between the glass samples should become clearer, and this will then provide information not only on which glass manufacturers are making which windows for which auto company, but also the compositions and therefore potentially the sources of

the raw materials used. From a commercial point of view, this information would be extremely sensitive; it is already well known that glass companies will purchase competitors glass for commercial purposes (Greenall 2007 pers. comm.). If a database of this type can inform not only what raw materials are being used but also who is supplying whom at a given time. In a prosecution case where a manufacturer is accused of using or supplying faulty goods, or in a case where a supplier is accused of using a fraudulently labelled window (i.e. labelled Pilkington when it is not Pilkington), a database of this type would provide a useful tool. In terms of a criminal investigation, if a large enough database was accessible then potentially fragments of unknown origin could be matched to a glass manufacturer, and from there potentially a car manufacturer, model and year of car.

In order for a database of this magnitude to be of use, it needs to have compositional data along with the manufacturing data. For example, elemental analysis to the trace element level, along with information about the RI and other physical features of the glass. This would be combined with the details about the specific window from which the sample was taken, such as the manufacturer, year of the glass, Dot number, and which window (windscreen etc). Also, any information about the car from which the sample came such as the make, model and year of the car would need to be recorded. One of the best ways to begin a database of this sort would be to work with an automotive glass repair or replacement company. The compiler would need to accompany the technician to each job and record all the necessary information before taking the sample. The downside to this approach would be the limited number of samples that could be collected in a day. Also, with this approach, the database would be skewed in favour of data and samples relating to windscreens (these have the highest replacement rate). From liaising with companies in an attempt to get samples for this pilot study, it was apparent that technicians are not prepared to add the extra data gathering to their jobs despite the relatively small amount of extra time it take. With this approach the permission of the vehicle owner would also need to be sought as data about their vehicle is being collated. Another potential source of samples would be auto vehicle scrap yards (where most of the pilot study samples came from); the problem with this is the lack of control over the available samples and information (many vehicles are ransacked and the necessary information such as date or glass manufacturer

may not be available). A problem that both of these approaches would have is that only one or two windows from each vehicle can be sampled, as the likelihood of all the vehicle windows needing replacement or being available for sampling is slim. If the glass could be recorded at source i.e. the glass manufacturers record the composition and window data, then this would provide the necessary glass information, but may not provide the vehicle information. Also, glass manufacturers and subsequently vehicle manufacturers may not be willing to voluntarily supply this information to a central database as they may view it as compromising their competitive edge. For example, Pilkington may not want Saint Gobain to have access to their compositional and potential customer information and vice versa.

So, although a database of this type has a high potential for investigative purposes, it would take a long time to compile as in most cases the archivist would have to collate the data from scratch. In the same way that forensic laboratories acknowledge the usefulness of a central glass database, they too claim that such a database would compromise their commercial/competitive edge (Lovelock 2007 pers. comm.).

In order to undertake a future study of this sort more samples would be required. Due to the large amounts of variation it would be sensible to start with one specific make and model, and then determine the amount of variation within one brand over a given length of time. For example, how much variation can be detected amongst Ford Foci 1990-2010? This could then be expanded based on the results to incorporate more Ford models and from there other makes of car. A future study of this type would need for each model of car a minimum of three samples per year. So, one model of Ford between 1990 and 2010 would require 60 samples. Ford manufactured 39 models of car between 1990 and 2010, so, to cover the Fords manufactured during this period, a minimum of 2340 samples would be needed. This would show the variation across a specific model and between models, but, it would be essential to know the country of origin (specifically the Dot No.) associated with each sample. For example, it would be necessary to know whether the three samples for a specific year all came from the same plant or different plants. Also, all the samples would need to be taken from the same window on each vehicle. In this way the variables of the research can be controlled and adjusted as the study progresses, rather than starting with too much variation and trying to understand it.

4.11 Conclusions

In conclusion, the samples of car glass can be differentiated by using a combination of the techniques used in this project. In terms of the forensic analyses of the glass the RI determinations were enough in this case to differentiate between the samples. In other words based on the RI, each sample of glass has been deemed to have come from a separate pane of glass. Although the changes in the RI are related to subtle changes in the major elemental compositions of the glass, this technique cannot give any information as to the nature of the raw materials used. The RI can be used to determine the classification of the glass i.e. whether the glass is architectural glass, container glass or vehicle glass, but, this is dependent to a certain extent on the nature of the database to which the RIs of the samples are compared. In terms of specific localised databases, they are often based solely on the samples that have moved through the laboratory compiling the database. In this way, the compositions routinely encountered can be relatively small and therefore, a glass that is different would be classed as unusual, where this may not be the case. In order to substantiate the accuracy of the databases, a vast number of samples from a range of different glass types would need to be analysed.

The samples analysed in this study were all taken from cars and many of the fragments were too small for any comparison of the physical features such as rib and hackle marks to be studied. If the samples of glass were physically larger then this approach may have been plausible. Most of the samples were of toughened glass and tempered glass characteristically forms small cubes of glass when broken. But, this in itself is not necessarily an indicator that the glass was a sample of automotive glass, because many architectural windows also utilise toughened glass.

Physical features and the optical properties of the glass are often used to determine a use category for unknown samples but as Figure 4-3 indicated, the overlap between the RIs of classification groups can be extremely high. So, although the RI is very powerful in discriminating whether samples have come from the same source, it is less useful at determining a classification for unknown glass. The physical features and RIs of the glass could be used to 'screen' samples if a suitable control has been determined (and this does occur in some laboratories).

This pilot study has shown the potential of using a combination of techniques in order to characterise samples of automotive glass. These analyses have allowed assumptions to be made as to the nature of the raw materials used and allowed patterns and interpretations to be made as to the source of particular elements within the glass i.e. whether the levels of a particular element are as a result of impurity from a raw material or from a deliberate addition. The samples of auto glass used in this study indicate a large spread in the data, despite this, three groups have been detected. These may be representing specific glass manufacturers or specific geographic regions i.e. more than one plant in a particular area sharing raw material resources. Alternatively this may also indicate a situation where two or more glass manufacturers have set-up and are sharing a plant facility. What the statistical analyses of the data has shown is that with this limited number of samples and with the large spread of the data involved, that the evidence can be interpreted in two ways; either, a large number of small groups or a small number of large groups. The three groups that have been chosen as representing ‘true’ groups are those which appear consistently in all the statistical analyses.

The trace elements in particular are showing large levels of variation, and some elements are showing correlations, for example, the rare earth elements (REEs). In terms of the elemental analyses, the samples from Asian manufacturers (Daewoo, Nissan, Toyota) are in many cases appearing as outliers to the rest of the groups. Likewise, the isotopic data has highlighted that some of the samples have a more ‘western’ Nd signature than others, if samples of quarry sand used in the modern glass industry could be analysed then it would be possible to potentially link the glass to specific sand sources. Equally so, the Sr isotope data, coupled with the Sr elemental data suggests that the majority of the Sr is being incorporated into the glass through the use of feldspars, and again, the signature of known sources could potentially be matched to specific glasses.

If a database were created which recorded the information about specific cars, glass manufacturers and automotive window compositions, it would have a huge forensic and commercial potential. As this study has shown it is possible to group the samples of glass; the availability of more information relating to the date and manufacturers of the samples would mean a greater potential of being able to identify

the source of unknown samples. In terms of a forensic investigation this would mean that unknown suspect glass could potentially be dated and sourced, and from this it may even be possible to determine the make/model of the car from which it originated. This information would also be of use to glass manufacturers, they would be able to determine where their competitors were sourcing their raw materials and would potentially allow more competition in the market place.

5 Discussion

This thesis set out to investigate what techniques were used in the analysis and subsequent interpretation of colourless glass, both archaeologically and forensically. It sought to determine not only which techniques were specific to which discipline but whether there is merit in using the techniques from one in terms of the other. Archaeological and forensic analyses of glass use different techniques to approach the question of provenance. Both disciplines seek to answer questions about the nature of the glass samples, but the purpose and final use of this information is very different in each case. For example, forensic glass analysis is used to determine whether two samples of glass match (Sanger 1985), and therefore can be said to have originated from the same pane of glass. If the glass found on the suspect matches the 'control' glass collected from the crime scene, then the suspect can be placed at the crime scene (Trejos & Almirall 2005). In archaeology, glass is analysed in an attempt to determine the source of origin and potential methods of manufacture (Wilson & Pollard 2001). Can the raw materials used to make the glass be identified and provenanced, thereby allowing suggestions to be made as to the nature of the glass industry in a given period, the status associated with glass, and potential trade patterns of raw materials, raw glass and finished artefacts? In short, the archaeological analysis of glass ultimately seeks to use provenance studies to identify the relationships between different groups of people through the examination of part of their material culture.

In terms of the forensic analysis of glass, the main techniques used are RI measurements and elemental analysis (usually SEM-EDS) (Duckworth et al. 2002). Both RI and density provide good discrimination between samples of glass, but it has been established that there is no real benefit in using both techniques and so most laboratories will employ one or the other; the more popular technique of the two being RI (Curran 2003). Usually the suspect samples are screened and only those with a RI close to the mean of the control sample will be analysed in detail (Harrison et al 1985). If further information or discrimination is required then elemental analysis of the sample is undertaken (Curran et al 2000). At this point, if both samples are indistinguishable from each other then they are assumed to be from the same piece of glass (Duckworth et al 2002). Physical methods of analysis can be employed if the fragments of glass are

large enough, for example, the fracture patterns in the glass can be analysed to determine how the glass was broken (Mecholsky 1994). Also, in some cases, again if the glass samples are large enough, it may be possible to determine whether two or more samples are from the same object or pane by matching the edges, as in a jigsaw (Howden 1981).

The archaeological analysis of glass uses a variety of techniques which look at the elemental and isotopic composition of the samples to determine the nature of the raw materials used in their manufacture (Hartmann et al. 1997). These techniques include SEM-WDS, SEM-EDS, X-ray Fluorescence, LA-ICP-MS and isotopic analysis. Depending on the type of glass being analysed i.e. fragments, complete objects or windows, will depend on whether other methods of analysis are used. For example, if a large fragment or pane of glass is being analysed it may be possible to determine what manufacturing process was used to make the glass i.e. Crown glass or cylinder glass, based on the size, shape and location of bubbles and other imperfections (Martlew 2008 pers. comm.). If an artefact or window has been painted then an analysis of the paint may provide further useful information.

Both disciplines approach the same fundamental question but from different angles, i.e. where does the glass come from? Also, both disciplines seek to link people and places through the analysis of the glass. This discussion will take each analytical technique and review the advantages and disadvantages of using each for the different disciplines. An assessment will be made as to whether the techniques that are seemingly specific to each discipline can be applied to the other and whether there is any merit in taking this approach.

Technique	Time needed for analysis
SEM-WDS	3 days
LA-ICP-MS	1 hour
HH-XRF	30 mins per sample
Isotopes	3-4 days
RI	10 mins per fragment

Table 5-1 Table showing time needed to perform each technique

5.1.1 SEM

SEM-WDS analysis is used where available in archaeology, and hardly ever, if at all, in forensics. This is mainly because although this technique provides very good data and reliable quantitative analyses, it is an expensive technique (Goodhew et al. 2001). Most establishments will have access to the cheaper SEM-EDS set-up which will provide semi-quantitative data, and if the machine is well run, quantitative analysis. The EDS system is good for rapid qualitative analysis of a sample, i.e. determining what elements are present in the glass, but due to the poor energy resolution of the detector, the X-ray peaks can be broad and this can limit the EDS's use in quantitative analysis (Goodhew et al 2001).

The main areas where the EDS system is weak i.e. peak separation, and peak to background ratio, are the strong points for the WDS system (Goodhew et al 2001). The WDS is set up to determine the concentrations of specific elements within a sample and this is one of the reasons why this technique is particularly useful within archaeological glass analysis. For example, a whole range of elements can be analysed allowing a variety of glass types to be examined at the same time i.e. several samples mounted in one block. This is also true of the EDS because it will determine which elements are present, but the WDS can determine the exact amounts of each element present in the sample (Goodhew & Humphreys 1988).

In terms of archaeological glass there is a wide variety of compositions and a study of the major and minor elements can be just as informative as a study of the trace elements. This was seen in the Christ Church analyses; the glass from different periods had distinct compositions which were clearly evident in terms of the major and minor elements (see section 3.12.1). Although, if only one specific type of glass is being analysed then this technique may not have such good discrimination between the samples. This project has been extremely lucky in that two distinct compositions of glass were present both relating to the 17th century, and enough of each were sampled from the collection to confirm that these two groups were genuine. As was shown in the comparison with David Dungworth's work on 17th century glass (section 3.13), the compositions from other locations can be far more dispersed, depending on the number of available samples.

Forensically, this technique would be more useful than EDS if fully quantitative analysis of the samples were required. The fact that EDS is used routinely in forensics when further investigation of glass samples is required shows that EDS is thought to have enough discriminatory power for the 'job in question' (Curran et al 2000). The problem with elemental analysis in forensics is that most samples of glass routinely investigated are modern and the variation in the major elements is very small, although there is some variation in the minor elements, as is shown in section 4.8.2. Overall, the standardisation of recipes and technologies used to create modern glass has meant that in terms of the major and minor elements there is often very little in the way of variation (Hickman 1981).

The advantages of using SEM-WDS analysis for forensic or archaeological glass include quantitative analysis of the composition, and the ability to target analyses to search for specific elements (Goodhew et al 2001). The disadvantages are the time involved in collecting the data (Table 5-1), the WDS is also not so good for qualitative analyses and although these are possible they too can take a considerable amount of time (Goodhew et al 2001). The other issue is the cost involved, it is far cheaper to do a rapid qualitative analysis of a sample with SEM-EDS than it is to analyse samples with the SEM-WDS. Therefore, the use of this technique for the analysis of glass will ultimately depend on the information that is required. For example, if the composition of the glass is known, or at least suspected, then the SEM-WDS can be used to quantify the elements present and this information can be used in conjunction with other information to begin to characterise the glass and the raw materials used in its manufacture. In terms of a glass where the composition is unknown this technique can still be used, but there is the risk that by choosing the elements to be detected, something interesting within the composition of the glass may be missed; for example, rare but important elements such as Ba or Au. SEM-EDS can be used to quickly determine what the elements of interest within the sample are, and from the semi-quantitative nature of the technique it is possible to determine whether the composition is unusual or, in the case of forensic analysis, warrants further investigation (FBI 2005a).

The main problems with relying on SEM analyses (both EDS and WDS) for either archaeological or forensic glass analysis, is that the samples may all appear very

similar in terms of the major and minor elemental composition, especially if glass from a particular period or a particular type is being studied, because the fundamental components of the glass are all very similar i.e. soda-lime-silica. This type of analysis is good for determining general information about the samples, i.e. whether it actually is soda-lime-silica glass. The EDS system is useful for rapidly determining the majority of the elements present but it cannot detect the lighter elements (Goodhew et al 2001). The WDS system can be calibrated to look for specific elements and it is capable of detecting lighter elements. Ironically, in forensics where the EDS is commonly used for the elemental analysis of the glass, the system cannot detect elements such as boron, yet it is with modern types of glass where the deliberate addition of elements such as boron are likely to occur, i.e. Pyrex.

Another problem area for SEM analyses in terms of both forensic and archaeological work is the issue of sampling. Complete archaeological objects may be too large for the sample chamber and sub-sampling from these may be problematic. Some of the fragments therefore encountered can be very small; this is especially true for forensic samples. Although samples can be mounted on stubs (without the need for using resin) this can cause problems, for example, if the surface of the sample is not flat, this can cause problems with the focusing of the SEM (Goodhew et al 2001). If the sample is mounted in resin, it can be polished flat; reducing the potential focusing issues, but this also has problems. For example, by grinding and polishing a certain amount of the sample is removed, and in the case of small samples these can be lost altogether. Table 5-2 represents the relative levels of sample destruction involved with each technique.

Technique	Destruction
SEM-WDS	Samples are mounted in resin, ground and polished thereby destroying small amounts of the sample
LA-ICP-MS	A pit c. 10µm across
HH-XRF	Non-destructive
Isotopes	c. 1g powdered glass
RI	Non-destructive (although fresh edge needed)

Table 5-2 Table of destructiveness of each technique

5.1.2 LA-ICP-MS

Solution ICP is one the common forms of sample introduction into the ICP-MS system (Dean 2005). This requires that the solid sample be digested in acid and filtered until it forms the required solution (Dean 2005). In terms of glass samples, because of the silica content HF is required for this process (Dean 2005), this means it is a difficult and potentially dangerous process, which will ultimately destroy the sample.

LA-ICP-MS is often used in the analysis of archaeological glass samples, but rarely for forensic glass (Curran et al 2000). This is because LA-ICP-MS is a destructive technique (Table 5-2) and although the amount of the sample that needs to be ablated is very small it has in the past been seen as too destructive to make this technique viable for forensic analysis (Trejos & Almirall 2005). Although, LA-ICP-MS is far less destructive than solution ICP-MS. LA-ICP-MS is a very accurate way of determining the trace element concentrations present in a sample. The laser ablation method of introducing the sample is destructive but far less so than in solution ICP where the sample has to be dissolved into a solution.

As mentioned above LA-ICP-MS is often used to study archaeological glass samples. The trace elements in the glass can reveal more information as to the nature of the raw materials used. For example, rather than just saying what the composition of the glass is, the relationships between different trace elements can give indications as to the ore sources used as a colourant (Tranter 2006). The technique requires that enough of a sample be present so that a small amount can be ablated, but the technique itself is relatively quick and easy to perform (Table 5-1) (Shortland et al. 2007). It does however require knowledge of an internal standard, usually either silica or calcium levels present in the sample. Generally the information gained from ICP analysis will be used in conjunction with major and minor elemental analysis, to allow a full characterisation of the glass samples.

Forensically this technique is not often used, although experiments are being performed to determine the potential of this and other laser related techniques, such as LIBS (Laser Induced Breakdown Spectroscopy) (Bridge et al. 2007). One of the main reasons why ICP is ignored by forensics is because of the destructive nature of the technique. Although, unlike with solution ICP where the whole sample is destroyed, LA-ICP-MS will only ablate a small amount, typically making a small pit in the surface

of the sample some tens of microns across (Dean 2005), the samples often encountered in forensics are too small even for this (Sanger 1985). In cases where there is a large quantity of glass present or the suspect still has large pieces of glass about their person, then the discrimination provided by this technique could be extremely useful. This technique could certainly provide detailed information about the composition of the glass and therefore whether the two glasses in question matched or not. However, any destructive analysis will completely destroy small samples, and the repeatability of the experiment could then be questioned. Even after the analysis of the glass, the samples need to be retained in case further analyses or re-evaluation is required at a later date (Lovelock 2007 pers. comm.). This technique could, however, have an important role to play in forensics.

This thesis has shown that there is a lot of potential in using trace element analyses for glass samples. Trace element analysis has shown that even modern samples with relatively tightly controlled recipes and manufacturing methods can be quite dispersed and different (see section 4.8.3). The Christ Church study (chapter 3) showed that the samples were attributed to the same groups irrelevant of the elemental analysis being used. The automotive glass study showed that analysis of the trace elements could further discriminate between the samples (section 4.8.3). The latter study highlighted the potential that a full characterisation of the glass could lead to samples from different glass manufacturers and/or models of car being identified, in the same way that the 17th century glass from Christ Church could be grouped independently. But, in order to achieve this potential a huge database would need to be created.

The usefulness of ICP as an analytical technique for glass analyses is not the issue, the logistics of how to make the most of it is. For example, with time and effort, and the creation of a large database, trace element analysis will allow for different types of glass to be identified and from there provenanced. The samples would need to be reasonably substantial, otherwise they would be destroyed and therefore the analysis would not be repeatable causing issues in terms of forensic work. Samples of control glass could quite easily be analysed using this technique (usually a large amount is collected, or is available for collection) (Datson 2007 pers. comm.) and this could allow the formation of a database, but it would probably suffer what most glass databases do, and that only samples coming through the laboratory would make the database and the

essential information needed about the sample would not always be available. Trace elemental analysis is a powerful tool in the study of glass, but, as with all of the techniques used in this research, works better when utilised in conjunction with other techniques.

The analyses of the trace elements within glass samples can reveal a lot of information regarding the origin of the glass (Shortland et al 2007), patterns within the data can indicate not only when glasses have come from a common source, but also highlight the potential signatures of specific raw materials (Tranter 2006). This could be particularly useful in terms of the forensic analysis of glass. For example, the trace element analyses of automotive glass in section 4.8.3 showed certain brands of vehicle beginning to group, such as, Ford. If this type of study were expanded and databases of automotive glass compositions were created, which were standardised and widely available to forensic technicians (rather than based solely on the glass routinely experienced in a particular laboratory), then glass from cars could potentially be matched to a manufacturer or make and model of vehicle. This would promote the usefulness of glass as an investigative tool, for example, if the glass found at the scene of a hit and run can be traced to a specific type of car, this will aid investigators searching for the suspect vehicle.

5.1.3 Isotopic Analysis

Isotope analysis is increasingly used in archaeology to study vitreous materials (Degryse et al. 2010). Using this technique it is possible to determine different compositional groups but also allows suggestions to be made as to the provenance of certain components (Degryse et al. 2006). Raw materials, especially rocks, have specific isotopic contents based on their geological age and geographical origin; different formation processes will also affect the composition (Degryse et al 2006). Over time the radiogenic parent isotopes will decay into daughter isotopes; because the time it takes for this to occur is known, the geological age of the rock can be determined (White 2007). Likewise, because rocks from specific locations have specific isotopic signatures, then the source of the rock can be determined by analysing the isotopes (White 2007). In terms of glass production, it is assumed that the raw material signature is not affected by manufacturing and technical processing and that therefore, the

finished artefact will contain the same isotopic signatures as the original raw material components (Henderson et al. 2005). This means that in theory, the isotopic signature of the glass can give an indication of where the raw materials originated. This technique will not give an age for the glass, but may suggest an age for the raw materials that were used to make the glass (White 2007).

In archaeological glass analyses, isotopic studies are used to trace where the raw materials came from and can, in a similar way to the elemental analyses, allow hypotheses to be created as to the nature of trade during the period the glass was produced. Also, isotope analysis can give indications as to how a particular element may have been introduced (Degryse et al 2010). For example, in natron glass, if the strontium isotopic signature is the same as modern seawater then the lime component in the glass is likely to have come from the inclusion of lime rich beach sand, i.e. marine shells incorporated in the sand (Huisman et al. 2008). Equally so, in plant ash glasses the lime is believed to have been incorporated with the plant ash, and that the plant reflects the strontium content of the soil in which it grew (Degryse et al 2010). The same ideas can be applied to modern glass, for example, the glass is made using synthetic soda and therefore, it will not be imparting lime or strontium to the glass. The strontium isotopic signature of the automotive glass in this study indicated older limestone deposits had been used (sections 4.8.4 and 4.9). This technique does have its disadvantages though; it is a very expensive technique to use and it may not yield any additional information beyond what the trace elements can give, especially if the signatures of the raw materials are unknown.

Forensically isotope analysis is not used in relation to glass studies. This research has shown that there is potential for its use in terms of intelligence gathering, i.e. the isotope analysis clearly shows differentiation between the samples, and with more work would potentially be able to link suspect samples to specific makes or models of vehicle. But, in the same way that more research and a large database is required to make the trace elemental analysis beneficial to the forensic world, the same would also be needed to make isotope analysis viable. At present the information gained from the technique would not provide any real help to the forensic world, other than differentiating between two glasses, which as has already been mentioned, the current 'forensic' techniques achieve. If however, long term research were undertaken to

catalogue the compositions of modern glass, or in fact to catalogue the isotopic compositions of known raw material outlets (modern glass manufacturers will use specific raw material suppliers), then isotopic analysis of glass fragments could potentially become a useful analytical tool. But, isotopic analysis is an even more destructive technique than ICP (Table 5-2), and this would pose problems for forensic work. Isotopic analysis requires c.1g of powdered glass sample, which needs to be dissolved in HF. Although solution ICP-MS is similarly destructive, LA-ICP-MS is far less so as only a small amount of sample is ablated.

In the future, isotopic analysis could become a very powerful forensic tool, but it would probably be of more interest to commercial glass manufacturers. A leading glass manufacturer said in confidence that a technique that would allow them to determine where their competition was obtaining its raw materials based on the composition of competitor's glass could be potentially very useful, in short, a form of commercial 'espionage' (Greenall 2008 pers. comm.). The technique could also prove useful in more general terms; if for example a distributor claims that a particular glass was manufactured and/or sourced from a particular location then the use of isotope analysis would be able to assist in (dis)proving the case.

Although isotopic analysis could in the long term become a useful forensic tool, it would only be of use in select circumstances. For example, the cost of the technique is high and the time needed to complete the analyses is long (Table 5-1), the technique is also highly destructive. ICP could provide similar information in a fraction of the time and if laser ablation were the method of sample introduction, then the destructive nature of the technique could be reduced.

5.1.4 RI

Refractive Index is the ratio of the velocity of light through a vacuum compared to through a medium (Curran et al 2000), in this case glass. As the light passes from air to glass, the velocity at which it is travelling changes and the angle at which the light is passing is altered (Curran et al 2000). RI is measured by immersing a fragment of glass in oil, of which the RI is known at a given temperature in sodium light (Foster and Freeman). The RI of the glass sample will remain constant despite the changing temperature, but the RI of the oil will vary as it is heated (Sanger 1985). At the 'match

point' the RI of the oil and the glass are the same for the given temperature. RI also changes depending on the wavelength of light that is being used to look at the fragments (Foster and Freeman). In terms of forensic analysis the standard 'set-up' is sodium light at 589nm (FBI 2005b).

RI analysis is routinely used in forensic glass studies for two main purposes. The first is to distinguish between two or more samples of glass (Harrison et al 1985); suspect glass is matched to control glass to determine whether a suspect can be linked to a crime. The second is to classify glass into use categories (Harrison et al 1985). This latter use of the technique results in broad arbitrary groups, but can be useful in deciding whether a piece of glass is likely to match the control, i.e. if the suspect glass is from a container, it won't match the control from a window. Also, categorising the glass can be useful for statistical studies relating to the types of glass most likely encountered in specific crimes. This is closely related to studies which monitor the amounts of glass found on clothing and again if these fragments can be categorised then conclusions as to how and when a particular type of glass is likely to appear on someone's person can be made.

The analysis of archaeological glass samples rarely, if at all, feature RI measurements. The main reason for this is because RI is seen to provide little useful information. The technique provides one number in answer to an analysis and this is effectively the sum of the techniques that have been used to produce the glass, i.e. it is affected by several factors including composition, manufacturing temperature, annealing processes, and mechanical stresses in the glass. This means that the RI number is very hard to use in terms of gaining information in relation to the source of the glass. In some cases the measurement of the RI can be extremely difficult to achieve depending on the composition of the samples, as is the case with the 17th century Christ Church samples (section 3.12.3). These samples, which were HLLA in composition, had very high RI properties and were outside the range of the standard oils used in forensic analyses. In a technique that relies on rapid screening of the samples, these, would have been flagged as anomalies and subjected to elemental composition, if further interrogation were deemed necessary (Becker et al. 2004). Where RI is seen as failing in terms of forensic analysis is the same point that makes the technique unattractive for archaeological analysis. In terms of modern glass, the control of the

manufacturing methods and recipes mean that the RIs of the samples are becoming tighter and tighter (Trejos & Almirall 2004) (this was not seen with the automotive glass in this study because most of the samples came from scrap yards and were potentially from older stock). This means that it is becoming harder to distinguish between different samples of modern glass based on the RI (Trejos & Almirall 2004). In archaeological terms there is known to be potentially huge variation between different samples of glass, and all the RI analysis will do is confirm this. Therefore, the relevance of using RI for archaeological analysis is questioned when all the samples will routinely be examined using elemental analyses.

A further potential archaeological use for RI would be to determine whether in an original historical window formed of several panes of glass, the different panes came from the same larger sheet of glass originally or whether each individual pane was created uniquely. This in turn could provide useful information as to the manufacturing patterns of window glass within a given period i.e. whether the windows for historic houses were created in bulk from a large sheet split into smaller panes, or whether each was fitted and crafted independently.

RI analysis is limited in that it can be time consuming, it takes c.10mins to determine the RI of each fragment and in a forensic study, three fragments of glass per slide are analysed and four slides per sample of glass are analysed. This allows very accurate statistical determinations to be made about the data so that it is robust enough to stand up in court, but it requires about two hours of machine time to run one sample. Admittedly, in terms of some analytical techniques, for example, Sr isotope analysis, this is fast, but the issue is that the analyst is present all the time, because individual runs are so short. If the analyst is only looking to see if the RIs of the sample are similar to the control i.e. within three standard deviations, then the technique can be very fast, as only one slide would need to be studied. Similarly if the technique is being used to determine use categories for the various samples this can be quite rapid. This technique also has quite expensive 'set-up' costs, the individual oils cost over £100 each and the GRIM 3 costs c. £40k. On the plus side, very small samples can be analysed in a non-destructive way, and the samples can be dried out and retained for further analyses. The nature of the GRIM 3 means that the size of the fragments can be measured, and the RI determinations are extremely accurate (to five decimal places). The downside to the

ability to analyse small fragments is that if fragments are too large, they need to be further crushed to enable accurate analyses. Also, if the fragments are not flat this too can pose problems.

RI is perfect for the rapid screening of samples, it can easily show whether samples are similar or not and the GRIM 3 program has the ability to compare the control and suspect samples, thereby performing a lot of the complex statistics. But, due to the large variation in glass compositions, the use categories into which samples are placed, based on the RI, are extremely arbitrary, and often involve large overlaps (Harrison et al 1985). This, however, is not the fault of the technique, but more of the use to which the information provided by the technique is put. If an arbitrary classification scheme for archaeological glass could be determined then RI could have potential, but as the results of this study showed different periods of glass production had similar RIs and the same periods had differing. More research into the RI of glass from specific periods or specific types of glass may reveal that this technique has potential and it too may be able to accurately classify groups. For example, the categories of glass currently available to the forensic world may be arbitrary because the system is based on the RI of glass encountered from a crime. If the RIs of a wider, more controlled selection of glasses were analysed, then it may be possible to determine more accurate glass categories based on RI.

5.1.5 Handheld XRF

Based on the data from the analyses of fragments of glass from Christ Church cathedral, Oxford, an analysis of one of the in-situ windows was undertaken using a Handheld XRF (HH-XRF), this is the first time this technique has been applied to in-situ windows. The use of this technique not only highlighted the composition of the glass used in the specific panes, but the data matched that gained from the fragment analyses. In other words, it was possible to tell which panes had been created in which art-historic period and in some cases by which artist, i.e. Price or Van Linge. This technique has potential for applications in both forensic and archaeological glass analysis. The technique is non-destructive and can be applied to fragments or larger objects or panes of glass. This would allow on-site analyses in both situations, thereby allowing a speedy assessment of glass. This is especially important if either large

amounts of glass need to be sampled and assessed, in order to determine which samples require more detailed analysis (for example on an archaeological site), or if, for example, there has been a hit and run and an assessment of the glass could provide an avenue along which the investigation could progress.

5.2 General Discussion

Although all of the techniques used during this research are ‘stand alone’ techniques, most work best when used in conjunction with other complimentary methods. For example, the study of the major and minor elements is only of use on its own if the glass samples are of distinct compositions, otherwise they will just appear the same, as in the modern samples. If the data from the SEM-WDS is used along with the data from the LA-ICP-MS, then a much clearer picture of the nature of the glass can be gained. Likewise, the use of the isotopic analysis can aid the identification not only of the sources of the raw materials used in the glass production but also the nature in which these components may have been introduced (Degryse et al 2010), for example, whether the lime component was added as marine shell or limestone. But, to use all the techniques without a clear research agenda would also be foolish, for example, the information gained from the isotopic analysis performed on the automotive glass samples only really confirmed the information gained from LA-ICP-MS analysis (section 4.9). If a database of all known compositions of raw material and all known glass recipes were available then techniques such as LA-ICP-MS and isotopic analyses would become invaluable to glass studies.

RI measurements offer a fast way to screen very small samples of glass (Curran et al 2000); this may have further use, again, if a suitable sized database can be created. Currently the use of RI for the classification of glass into use categories is very arbitrary (Hickman 1981) and the application of this technique in its present state would offer little to archaeology. The only way that RI may be of use is if only extremely small samples of glass can be taken, i.e. from a museum object or a stained glass window during conservation. RI could then potentially give an indication of the type of glass i.e. whether the glass is likely to have high or low CaO contents of whether it is expected to be Roman/Medieval, but again, a database of RIs for these glasses would need to be created. Realistically, if a piece of glass from a collection can be sampled then the

sample will probably be large enough for elemental analyses. Also, in terms of archaeological glass any small slithers which may be taken for RI are likely to be from the outside surface of the glass and therefore are more likely to have been affected by weathering or degeneration of the sample. The RIs used in this study were all taken from the bulk of the glass sample, this is a luxury that is not always possible, and any analyses of the RI would have to take this into account.

One of the major problems with the use of RI for the analysis of glass is that the data provided is in the form of a single number (Trejos & Almirall 2005). This number represents a combination of effects, for example, the composition of the glass, the temperature at which the glass was formed, the annealing process to which the glass was submitted, and any stresses that may be present (Curran et al 2000). Although if these individual attributes were considered, it may be possible to predict the RI of the finished glass, it is impossible to work the other way and isolate these features from the RI number gained through the analysis. The information gained from RI analysis is in a sense uni-directional, the component parts which contribute to the RI cannot be identified from the final number. In the current state of forensic glass analysis, a uni-directional approach is all that is required, because it is the comparison of the RI numbers which forms the end result of the analyses. Whereas, a technique such as LA-ICP-MS, is multi-directional, the composition of individual raw materials can be analysed to predict a final glass composition (Varshneya 2006), and the glass composition as determined by the ICP can be split back into its contributory parts. Although there will be slight modification of the raw materials during the glass manufacturing process (Varshneya 2006), an elemental technique can give an indication of what the raw materials may have been without the need to rely on a database for comparison.

In terms of archaeological glass analyses the current techniques used provide information as to the composition of the glass. The techniques are often destructive, but can potentially give a geographical origin for the material (Degryse et al 2010). This can lead to discussions and interpretations about the status of the raw materials and the finished objects and subsequently hypotheses regarding the trade in glass for a given time. Different periods have different glass compositions and numerous glass studies focus on specific periods of production. If small samples can be taken then a rapid

screening technique such as RI could be potentially helpful. If a specific period of glass history is under consideration and a suitable database of RIs can be made (assuming that specific periods will have a specific RI range), then this technique could potentially screen large numbers of fragments to determine which are within the period of interest and therefore warrant further investigation. This relies on the classification of archaeological glass into suitable RI groups, which may not be possible. It was seen in the analysis of various archaeological glasses (section 3.12.3) that Roman, Egyptian, Medieval and 17th century glasses were all distinct from each other, but, the Victorian samples were similar to both the Egyptian and the Roman. Rather than saying that the RI does not work for archaeological glass, it may be that, like the other techniques, its use would be dependent on the research project in question. For example, RI could quickly screen the Victorian/Modern samples from the Medieval and 17th century, and therefore may have some potential use in terms of a project relating to stained glass. On the other hand, if Roman artefacts were being studied and natron and plant ash glasses were in question then again, the RI ranges could provide a quick screening method. RI would be limited if one was attempting to determine Victorian copies of Egyptian or Roman glasses because as the Christ Church data shows there is an overlap between these groups. RI would be a good technique to use if individual panes of glass from a single window were being analysed to determine whether the panes originally came from a single large sheet of glass or not.

Forensically, RI is one of the best methods of approaching the question being asked of the glass analyst. Do two samples of glass match? RI is a quick non-destructive method of answering this question when very small fragments of glass are involved (Curran et al 2000). The archaeological techniques used to study glass will also, to a certain extent, answer this question but will take longer and cost more in the long term. If the nature of the question were changed slightly, i.e. the glass was used in an attempt to gather intelligence, then as evidence it could potentially offer more than just discriminating between samples and linking a suspect to a place. This research has shown the potential of the archaeological techniques to offer information relating to the provenance of the glass. There is a potential to be able to distinguish the glass from different manufacturers, assuming a large enough database could be created (section 4.10). With the aid of the glass manufacturers, this in turn could lead to the ability to

link glass compositions with specific car makes. For example, glass manufacturers will have information relating to who they were supplying in a given year, and they may be willing to contribute past information to a central database, if not current details. The use of an archaeological approach to forensic glass analyses would rely on the development and maintenance of a central database. For example, small scale local databases based on the samples that have passed through a specific laboratory will only provide information on a localised scale. Patterns relating to large scale glass manufacturers and their commercial operations will not be apparent based on local level research, as was highlighted by the pilot study (chapter 4). In terms of intelligence gathering and interpretational work in either field (forensics or archaeology) compositional analyses will always be more useful than RI, because the techniques can be applied in either direction. The composition of a glass can be predicted from a combination of raw materials and an analytical technique which can determine those compositions can be used to predict the raw materials. RI cannot do this, it can only compare two or more RIs.

This research has focused on two specific case studies, stained and painted glass from Christ Church Cathedral, Oxford (chapter 3) and modern car windows (chapter 4). The reason these two particular studies were chosen was because a certain amount of control over the data was needed in order to create a coherent research project. The samples from Christ Church had a very specific datable history, and likewise the auto samples had dates, glass manufacturers or auto manufacturers associated with them. In this way, it was possible to interpret the data and the patterns within it. Architectural window glass was considered for the forensic study, but, there was no way of knowing who had made the glass and when, only when it may have been replaced if this was recorded.

Architectural window glass would be an interesting case study because there are so many different variations. For example, modern architectural glass is designed to be more than just a window, it has to agree with the surrounding architecture and provide a variety of functions (Louw 2007). Windows in modern buildings can in some cases form entire walls (Louw 2007); much of the glass in high-rise office blocks has been treated to be self-cleaning (www.pilkington.com 2010), and currently blast proof glass is being developed (www.pilkington.com 2010). Architectural glass has always had a

dual purpose; to let in light and to protect a room from the external environment (Scott 1858). Understanding the uses to which the glass is being put, shows the importance of proper design in terms of the physical and chemical properties of the glass. Architectural glass has been in use since Roman times (Louw 2007), and the use of glass within buildings has at times been very specific. It is these properties which would make the study of architectural glass interesting, for example, is the glass just soda-lime-silica? Has it been treated in some way, either with decolourisers, or painted, or coated? Is the glass patterned, or has it been strengthened in some way? An understanding of the compositions and properties of different architectural glasses can impart information relating to the status of buildings. For example, the Bull's Eye in Crown glass was originally the worst piece of the glass table or disc and would therefore have been put in locations of little importance such as kitchens; whereas, today it is seen as decorative feature and is often present on front doors (Martlew 2008 pers. comm.). If architectural glass can be dated and provenanced then it can aid restoration work. For example, modern glass would not necessarily look sympathetic and in some cases may even look out of place on a historical building (Martlew 2008 pers. comm.). A complete study of architectural glass would be a long term, large scale project. There would be more complications in terms of getting the relevant data about the date and manufacturers of the glass, but once the information had been collated it would be of use both forensically and archaeologically. In fact, architectural glass is one of the areas where both forensic and archaeological glass studies would come together, because historic buildings can often be the target of vandalism.

Aside from the local databases of glass held by specific laboratories, which include information on the RI and occasionally on the composition of glasses, there are two large general purpose databases of glass. INTERGLAD (Japan) and SciGlass (USA) have been developed for use by professionals in the glass industry. INTERGLAD is orientated towards the needs of the industry, while SciGlass is more focussed towards glass science (Mazurin & Priven 2006). These two databases have collated the data from published research on various glass compositions, and created large scale databases which address the scientific and technical properties of various experimental glasses (Varshneya 2006). These sources of information are extremely useful if a project is being planned about a specific type of glass or the specific

properties of a glass need to be understood for a new application. But, these resources are mostly based on experimental glasses and therefore do not cover the elemental compositions in detail and a lot of the information is limited by what can be gained from the articles in which the work is cited. For example, if an article about a specific glass only quotes the RI and density of the glasses, then this is all that is recorded in the database for those glasses (Mazurin & Priven 2006). Unfortunately in their current state, despite having information on over 267,000 glasses in each database (both databases will often cover the same glasses), the use of these databases for forensic or archaeological applications is limited. As has already been discussed the types of glass likely to be encountered in either context is very limited, and so the composition and properties of scientific glasses and specific use glasses will not necessarily be relevant. These databases do offer the opportunity to search for specific properties of the glass or to predict the nature of certain experimental glasses (Mazurin & Priven 2006), and this information could prove useful to further archaeological or forensic glass research. The fact that these resources do already exist is encouraging, it means that they can be built on. If the programmes exist to contain searchable glass databases, then all that would be needed is the addition of a few extra specifications, such as major, minor and trace elements and isotopic compositions (the databases already contain some information regarding RI and density). It would then be a case of adding information relating to archaeological and historical glass to the existing databases.

Science based glass studies often focus on the physical properties of the material, consideration of the optical properties are made, but a lot of the research will focus on the strain points or the electrical properties (Varshneya 2006); in other words the technical side of glass science. A better understanding of all the properties involved in glass science will allow for a better understanding of the application of specific glasses to specific tasks, and will therefore aid in the classification of glasses. For example, fragments of glass found on an archaeological site may be assumed to be for a specific purpose, but an understanding of the physical properties which that type of glass would have may lead to a more accurate interpretation of its use. This may be especially true in situations where the original context or structure of the glass has been lost. For example, glass found in WWI trenches can be melted or fused to other items, in these cases the original use for the glass is not obvious, but an understanding of the

physical properties of that particular glass may be able to give an indication as to its original use. The same principal could be applied to glass from forensic cases where a fire or other high temperature event has been involved.

The provenancing of glass, forensic and archaeological is about understanding the context in which the glass was found and relating this to the context in which it was made. Both disciplines rely on being able to take small unidentifiable fragments of glass and relating them to objects, areas, and people. In forensic terms if the glass can be identified not just as window glass or automotive glass, but as coming from a specific building or vehicle, then the link between suspect and place is stronger, but also there is potential to trace a suspect's movements if a crime scene is not obvious. Or, if glass is found at the scene of a hit and run accident and this could potentially be traced to a specific model of car, it will aid in the investigation. Equally so, if a method of classifying fragments of archaeological glass could be defined, this would aid the interpretation of unknown fragments. Do all historical glass objects have the same RIs as historical windows for example, and can these even be classified through the investigation of RI, as it is in modern glass? Although this research has shown the potential of using XRF in the field to analyse in situ glass, this method relies on a minimum size of sample (9mm), whereas a screening method using RI could utilise very small fragments c.500µm in size, but would need the development of an 'in the field' piece of equipment.

Ultimately, the study of glass in any discipline relies on the use of a specific research question or agenda. The knowledge gained from specific techniques means nothing without an adequate research context. *"knowing the composition of a glass vessel only has real value if it forms part of a comparative study that incorporates both scientific and archaeological research questions"* (Willmott 2002: 9).

6 Conclusion

The fundamental question asked in both forensic and archaeological glass studies is ‘where does the glass come from?’ This is approached by the two disciplines in very different ways. Generally speaking, forensics seek to match different glass samples to each other, whereas, archaeology seeks to match different glass samples to their origin. The disciplines use different techniques to each other to answer their slant on the question. The strengths of the different techniques are also geared towards the way the different disciplines approach the provenancing question. For example, the techniques used in forensic glass analysis are good for discriminating between two samples, whereas the techniques used for archaeological glass analysis are good for determining the composition and potential geographical origin of samples. This thesis aimed to determine what the different techniques used by the different disciplines are. Also, it sought to determine whether it was possible to utilise the techniques used by one in the other, and whether there were any real merit in doing so.

6.1 Evaluation of Techniques

In order to evaluate the usefulness of the techniques to the alternate discipline, it was necessary to determine the similarities and differences in approach to glass research between the disciplines, for example, the size of the samples. In forensics the samples can be very small, c.500µm, whereas archaeological samples by comparison are large. The analytical techniques used reflect this; if large samples of glass are available then the archaeological techniques can be used. Likewise, if tiny slithers of glass are being analysed then forensic techniques can be used. Although this research has shown that the techniques used in both disciplines have merit and can potentially offer a lot to the other discipline, there are logistical issues involved, sample size being one of them. Another consideration is the cost of the technique, for example, where a large of volume of samples needs to be analysed, as in some forensic cases, the use of LA-ICP-MS or isotope analysis may prove expensive for relatively little gain. This is especially true if the forensic analyst is only seeking to match two samples of glass to each other. Equally so, for large numbers of samples, some of the more time intensive techniques may prove

inefficient. The choice of technique used is therefore dependent on what is required from the analysis.

Although this research has shown that the archaeological techniques can be applied to forensic samples, they are an expensive and time consuming way of defining whether two samples of glass match. If the forensic world were to re-evaluate the potential of glass as evidence, then the information gained from the archaeological techniques would be invaluable. The archaeological approach to the question of provenance involves determining the origin of the raw materials in the glass; in a forensic case this could potentially lead to a glass manufacturer, car manufacturer and even a specific car. Alternatively, if a suspect is found with glass on their person, this could be used to retrace their movements and potentially ‘find’ a previously unknown crime scene. This study has also shown that the use of RI could potentially be of use in archaeology if more research was undertaken to determine the extent of RIs for different categories of archaeological glass. For example, if the RIs of specific glasses were shown to be consistently different then a screening technique using RI could potentially be developed to determine the originality of glass artefacts. In other words, this method would be of use in the art-historic world to help determine forgeries from genuine glass art. Also, the technique of RI could be of potential use to architectural historians. For example, if someone wanted to know whether the individual panes in a specific historic window all came from a single sheet of glass or not, they could use RI to determine this.

6.2 Logistics

The major issue therefore, is not determining the usefulness of the different techniques to the different disciplines but rather the logistics of using the different techniques. As has already been mentioned the size of the sample may pose problems depending on which technique is used. The destructive nature of some of the techniques would be an issue in forensic analyses because the repeatability of the experiment is lost due to the destruction of the sample. This would mean that either small samples could not be analysed or that an analysis would need to be extremely robust to justify the destruction of the samples. This latter point would require a well defined series of research questions before the analyses were completed because the order in which the analyses were performed would be imperative. The non-destructive techniques would

need to be performed first and the research questions would then need to justify the need to use destructive techniques. For example, if only discrimination between the samples is required, there is no need to necessarily perform trace element or isotopic analysis.

Although some of the archaeological techniques are destructive in nature, this can be kept to a minimum, and if it were known in advance that destructive analytical techniques were required in order to gain intelligence information from the sample, then a sampling strategy could be put in place where a larger volume of sample is initially collected. For example, from a hit and run incident, there may be a large quantity of broken glass available for analyses. If only a small amount of sample is collected it may not be possible to use some of the techniques, for example, isotopic analyses requires c.1g of powdered glass sample. Likewise, with LA-ICP-MS, if the sample is too small it will not be possible to ablate any.

In terms of archaeological samples, these can sometimes be too big, especially for use with some of the non destructive techniques, such as RI. In these cases it is necessary to remove small pieces of the glass for analysis and this in itself causes further issues.

6.3 Characterisation

In archaeological studies the characterisation of the glass is important; it is the identification of the relationship between the elements which allows for successful provenancing to be performed. In order to successfully characterise the glass, all of the major contributing components need to be identified and quantified. Therefore, techniques which can determine the levels of Na₂O and other light elements in the glass are more useful than those which cannot. In terms of classifying glasses into use categories, the archaeological approach is entirely visually based, whereas, forensics attempts to use RI and density measurements to achieve this. There is potential in using the forensic approach for archaeological samples, for example, physical properties of glass could be linked to specific typologies, and this information will in the long term allow random fragments of glass to be classified. Unknown fragments found on an archaeological site could have their physical properties i.e. RI determined and linked to a specific end use or use category. Also, if the fragments came from the same sheet or

batch of glass the RI could be used to determine this in a speedy non-destructive manner.

Both archaeological and forensic glass analyses have the potential to learn from the other discipline. But the gain and trade in knowledge is dependent on the creation of better, more accessible databases. The current databases which exist are either geared towards the local area, or are geared towards glass science and engineering, or are commercially sensitive. In order to move forward in glass provenancing studies the information about compositions, optical and physical properties of different glasses need to be widely available and easily accessible. The skills and expertise of the two fields of interest may also find a common ground in the commercial glass sector rather than in their individual areas. For example, the ability to trace the raw material source of a modern glass, and to then be able to determine why it has better or worse properties than a competitor's glass would be of interest to glass manufacturers. Equally so, the ability to analyse and then recreate a historical glass would be of interest to building and heritage conservators.

6.4 The Two Studies

This thesis contains two major studies, one archaeological and one forensic. These studies are original pieces of research in their own right, in terms of the archaeological project examining stained and painted glass from Christ Church cathedral, samples of glass were compositionally characterised for the first time. The analyses of these samples indicated that the glass from different phases of the cathedral's history had very different compositions. These compositions related not only to specific periods i.e. HLLA glass associated with the 17th century. But, more importantly, could be related to specific artists within those periods, for example, the 17th century glass could be further subdivided into the work of Price and the Van Linges. These results were then used to analyse an in-situ window in the cathedral (the Jonah window), and this meant the identification of original panes of glass from later restorations. It was also possible to determine when the restorations had occurred, for example, Price and Modern restorations of Van Linge work. It was also possible with this method to identify where Price had restored a different Van Linge window and these sections had later been used to restore part of the Jonah window.

The second study which used both the forensic and the archaeological techniques to analyse glass samples, took fragments from car windows. This study highlighted the complex nature between the glass manufacturers and the car manufacturers. The process of creating glass for vehicles involves not just the manufacture of the glass but also the addition of all the individual trimmings which may be required. Analyses of the glass samples indicated that potential groups could be created from the data and that these could be related to specific raw material sources. The study identified the need for a database of both raw material sources and glass compositions to be able to use glass evidence to its full potential in terms of intelligence gathering.

6.5 Further Research

In terms of the work at Christ Church, continuing research into the compositional characterisation of the fragments in the collection needs to be undertaken. In this way, it may be possible to begin to define specific windows from the Van Linge scheme based on composition. Further research on the fragments will be able to highlight which glass is being reused i.e. a distinctly Victorian pattern may have a Van Linge composition, and which windows are being restored such as painted fragments which look like Van Linge but compositionally are very different. This work should also be expanded to look in more detail at the coloured glass within the collection. The next stage is to continue developing the use of the HH-XRF for work on in-situ glass windows. The pilot study looking at the 'Jonah' window demonstrated the potential of this technique, and this work should be expanded to look at other windows within Christ Church, for example, Bishop King (also 17th Century), the Latin Chapel windows, and the Becket window; to what extent have these windows been restored, renovated and changed? This work could also be expanded to look at the other in-situ Van Linge windows in Oxford and further afield, such as Lydiard Park or Wroxton Abbey.

Also, to further the more general applications of the research, the next stage would be to begin to create a comprehensive glass database aimed primarily at the 'provenancing market'. For example, the database would be focussed more towards the compositions of glasses likely to be encountered in archaeological or forensic settings, rather than specialised scientific glasses. The database would also need to contain

information relating to the compositions of raw materials from various locations. If this could be combined with batch calculation software which allowed the user to predict what glass signatures could be expected from specific combinations of various raw materials, this would allow a powerful interpretive tool to be created. This sort of database would be of use both forensically and archaeologically as it would allow the identification of glasses, their associated raw materials and potential locations from which the glass may have originated. In order to achieve this, further specialised studies of glass would need to be undertaken.

The key to taking the research further would be to start with a small very specific database, for example, focussing on the compositions of a given make and model of car for a series of years. This could then be expanded to incorporate other models from the same make. A larger number of samples would be required to give an appropriate overview of the compositions for a given make in a given year. Equally so, if more sites providing a rich source of datable historic window glass or container glass could be found, then these could form the basis of a detailed archaeological glass database.

Glossary

Archaeological

Biblical Types and Anti-types – these are two or more different Bible stories which reflect the same message, for example, Jonah and the Whale is the type of the Resurrection (the anti-type). The anti-type is always a ‘bigger’ and more glorious event than the type.

Bull’s Eye – centre bubble from a table of crown glass, this is where the pontil would have been attached.

Clerestory – a row of windows in the upper part of the wall of the nave of a church above the roof of the aisle.

Cullet – fragments of glasses which are recycled by being added to subsequent glass melts.

Decolouriser – a component that is added to the glass melt in order to neutralise any colour that may be imparted by impurities in the raw materials.

Devitrification – the crystallisation or formation of mineral phases within a glass.

Flashed Glass – where a layer of coloured glass is fused to colourless (or white) glass.

Geochemical Fingerprint – this is the composition of the raw materials used in the production of an artefact.

Geological Signature – often described as the ‘chemical fingerprint’ of an artefact, it refers to the chemical composition of the raw materials used in the manufacture of the artefact.

Grisaille – clear or grey glass painted with simple repeated designs, usually foliage, in brown or black.

Halophytic Plant Ashes – soda rich plant ashes.

Iconoclasm – the destruction of religious images or objects.

Idolatry – the worship of idols.

Inter-source Variation – this is the variation between different sources of a material.

Intra-source Variation – this is the variation within a single source of a material.

Isotope – one of two or more atoms with the same number of protons in the nucleus but a different number of neutrons.

Painted glass – where the surface of the glass has been decorated using enamel paints.

Poise – the measurement of viscosity. $1 \text{ poise} = 1 \text{ g.cm}^{-1}.\text{s}^{-1}$

Pot Metal Glass – where the colour runs throughout the glass and is created by the inclusion of transition metals, such as copper, in the melt.

Potash – a potassium rich ash.

Provenance – the source of origin of a material.

Quarry – a small diamond shaped pane of glass.

Silver Stain – where silver compounds mixed with a suitable carrier medium was painted onto the glass surface and then fired to produce a range of colours from pale yellow through bright yellow to dark brown.

Stained Glass – where the colour is contained throughout the glass matrix.

Forensic

Bait – a hot metal bar or ring.

Benefaction – a process which reduces the impurities in a raw material.

Bleib – large sulphur bubbles in the glass.

Borosilicates – glasses containing boron oxide as a major component.

Control Sample – sample collected from the scene of the crime.

Debiteuse – a 3m long clay block with a slot in the centre.

DOT No – this is the number on automotive glass which indicates which plant the glass was manufactured in.

Fingerprint – an impression of the pattern of ridges on the inner surface of the end of each finger and thumb.

Gob – a small quantity of molten glass.

Laminated Glass – where two or more sheets of glass are fixed together with a polyvinylbutyral (PVB) layer in between.

Music Lines – streaks on sheet glass caused by impurities being pulled as the ribbon of glass is created.

Parison – a blank mould.

Pyrex – a common borosilicate glass, often used in kitchenware because of its heat resistant properties.

Refractive Index – is measurement of the ratio of the velocity of light in a vacuum to the velocity of light in a medium.

Regenerative Tank Furnace – where raw materials continuously enter at one end and the glass melt is continuously removed at the other.

Seed – small bubbles in the glass.

Shawl – length of flattened cylinder glass.

Stones – undigested sand grains.

Suspect Sample – sample taken from an individual suspected of being involved in a specific crime.

Toughened Glass – where the glass has been treated to impart extra strength.

VIN – Vehicle Identification Number.

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Appendix A

A Defence of the Historicall use of the painted windows in Christ Church ag^t a Banburie Brother Sloane MS 1435 pp122-124 (the lines highlighted in red appear in both versions of the poem but in different places)

You that prophan'd our windowes with a Tongue	1
Set like some Clocke on purpose to goe wrong	2
Who when wee were at Service sigh'd because	3
You hear'd ye organs musick not ye Dawes	4
Pittying our solemne state, shaking ye Head	5
To see no Ruines from ye Flowre to th' Lead	6
To whose pure Nose our Cedar gave offence	7
Crying it smelt of popish Frankincense	8
Who walking ove our Marble scoffing said	9
Whose Bones are underneath these TombeStons laid	10
Counting our Tapers works of Darknesse, and	11
Choosing to see priests in blew Aprons stand	12
Rather then in rich Coapes, which shew ye Art	13
Of Sisera's Prey embroidered in each Part	14
Then when you saw the Altars Bason sed	15
Why's not ye Ewer too on ye Cupboards Head	16
Thinking our very Bible too prophane	17
'Cause you ne're bought such Covers in Duck Lane	18
Loathing all Decencie as if you'd have	19
Churches as foule & homely as the Grave	20
Had you one Sparke of Reason you would find	21
Your selves like I dolls too had eyes yet Blinde	22
Tis only some base niggard Heresie	23
To think Relligion loves Deformitie	24
Glory did never yet make God ye Lesse	25
Neither can Beautie defile Holinesse	26
What's more magnificent then Heaven, yet were	27
Is ther more Truth or Puritie then ther	28
My heart doth wish twere Possible to see	29
Each Church built up Iet & Porphyrie	30
To have our Halls & Galleries outshine	31
Churches in Beautie is to deck our Swine	32
With Orient Pearle, whilst ye deserving quire	33
Of God & Angells wallowes in ye mire	34
Our decent Coapes only Distinction keepe	35
That you may know ye Shepeard from ye Sheepe	36
As Gaudie Letters in the Rubrick show	37
How you may Holy Dayes from Lay dayes know	38

Remember Aarons Roabes & you will say	39
Ladies at Masques are not so rich as they	40
Then are the priests words Thunder Claps when thee	41
Is lightning like ray'd round with Mdiestie	42
May every Temple shine like those of Nile	43
But still bee free from Rat or Crocadile;	44
I know you'le cry both Priest & Church should bee	45
The Solemne Patterns of Humilitie	46
Doe not some boast of Raggs Cynicks deride	47
The Pompe of Kings but with a greater Pride	48
Meekenesse consists not in ye Cloaths, but Heart	49
Nature may bee vaigneglorious well as Art	50
Wee may as lowly before God appeare	51
Drest with a glorious Pearle as with a Teare	52
In his high servile wher the Starrs & Sun	53
Doe but Eclipse, ther's noe Ambition,	54
You dare admit gay paint upon a wall	55
Why then on Glasse ist held Apocryphall?	56
Our Bodies Temples are looke in each eye	57
The windows & you needs must Pictures spie	58
Moses & Aaron with the Kings Armes are	59
Daub'd on the Church when you Churchwarden were	60
Yet you n'ere fin'd for Papist, shall wee say	61
That Banburie is turn'd Rome, because wee may	62
See th' Holy Lambe, & Christopher, nay more	63
Th' Altar Stone set at a Taverne Doore	64
Why can't the oxe then ith Nativitie	65
Bee Imagd forth but Popish Bulls are nigh	66
Our Pictures to no other end are made	67
Then are your Time & Sith, your Death & Spade	68
To us they're but memento's which present	69
Christ best, unlesse his word & sacrament	70
If 'twere a Sin to set up Imagerie	71
To get a Child were flat Idolatrie	72
The models of our Buildings would bee thus	73
Directions to the House, Ruines to us	74
Has not each Creature wich has duly Birth	75
Something that may resemble Heaven or Earth?	76
Suppose that ignorant Heathen once did bow	77
To Images, may wee not see them now	78
Shall wee love Darkness & abhorre ye Sun	79

'Cause Persians gave it Adoration	80
Or Plant noe Orchards, because Apples first	81
Made Adam & his lineall race accurst?	82
Though wine for Bacchus, Bread for Ceres went	83
Yet both are now us'd in the Sacrement.	84
What if that these are Popish Reliques? Few	85
Windowes but are elsewhere but these are new	86
And so excell all former that your Face	87
Comes short even of the outside of our Glasse	88
Colours are here so mixt that RaineBowes bee	89
Compar'd but Clouds without varietie	90
Art here is Natures Enmie this is hee	91
(Not Paracelsus) that by Chimistrie,	92
Can make a man of Ashes, if not Dust	93
Producing off Springs of ye mind not Lust	94
See how he makes his maker & doth Draw	95
All that is meant i'th Gospell or the Law	96
Looking upon the Resurrection	97
Mee thought I saw ye blessed vision	98
Wher not his Face was only drawne but minde	99
Which not with Paint but oile of Gladnesse shin'd.	100
But when I view'd ye next Pane wher wee have	101
The God of life transported to the Grave	102
Light then is darke all being so dull & dead	103
As if that part o'th window were all Lead	104
Jonas his whale did all mens eyes so foole	105
That they'd have beg'd it for th' Anatomie Schoole	106
That he saw Ships at Oxford one did sweare	107
Although the Thames will hardly beare	108
Another soone as hee the Trees espied	109
Thought them ith Garden on the other side	110
See in what Awe Moses his Rod doth keepe	111
The Seas as if a Frost had glas'd ye Deepe	112
The Raging waves are to themselves a Bound	113
Some cry Helpe, Helpe, or Horse and Man are drown'd,	114
Shadowes for Substance every wher doe passé	115
You'd thinke ye Sand were in an Hower Glasse	116
You that have liv'd with Surgeons have you seene	117
A Spring of Blood forc'd from a swelling veine,	118
So from a Touch of Moses Rod does Jumpe	119
A Cataract, the Rocke becomes a Pumpe;	120

At sight of whose o'reflowing many get	121
Themselves away for feare of being wet	122
Have you beheld a sprightly Lady stand	123
To have her Beame drawne by the painters Hand.	124
Such lively looks & Colours, such a Dresse	125
King Pharaoh's Daughters Image does expresse	126
Looke well upon her Gowne and you will sweare	127
The Needle not ye Pencill had bin ther	128
At sight of her some Gallants doe dispute	129
Whether i'th Church tis lawful to salute	130
Next Jacob kneeling wher his kidskins such	131
As it might well cozen ould Izaacks touch	132
A Shepeard seeing how Thornes 'twine'd about	133
Good Abrahams Ram would needs have help'd it out	134
Behold ye Dove descending to inspire	135
Th' Apostles Heads with cloven Tongues of Fire	136
And in a superficies ther you see	137
The grosse Dimensions of Profunditie	138
Tis hard to Judge which is best built or higher	139
The Arched Roofe i'th window or ith quire	140
So beasts as in the Arke are lively donne	141
Nay you may see the Shadow of the Sun,	142
Upon a Landskip if you looke a while	143
You'd thinke the Prospect at least forty mile,	144
Ther's none needs now goe Travell they may see	145
At home Jerusalem and Niniveh	146
A Sodome now in Flames one glaunce will Dart	147
Farther then Linx with Galilæus Art	148
Seeing Elijahs Chariot wee feare	149
Ther is some firie Prodigie ith Aire	150
When Christ to purge the Temple holds his whip	151
How nimble Hucksters with ther Burdens skip	152
St Peters Fishes are so lively wrought	153
Some cheapen them and aske when they were caught	154
The Angells with ther Lutes are done so true	155
Wee doe not only looke but hearken too	156
As if ther sounds were Painted, thus the witt	157
O'th Pencill has drawne more then ere could sit	158
Ther's motion painted too, Chariots so fast	159
Run, that they're always gone though never past;	160
Thus, as in Archimedes Sphere wee may	161

In a small Glasse the universe survey	162
Such various Shapes are i'th Imagerie	163
Each, Age and Sexe may ther owne feature see	164
But if the windows cannot shew your Face	165
Looke under Foote, the Marble is your Glasse	166
Which loe for more then ornament is ther,	167
These stones may teach our eyes to shed a teare;	168
But though these various shades delude ye sense	169
They never worke upon the Conscience	170
They cannot make us kneele wee are not such	171
To thinke ther's Balsame in their kisse or touch	172
The saints themselves for us can doe no good	173
Much lesse ther Pictures drawne in Glasse or wood,	174
They cannot seale, but since they signifie	175
They may be worthy of a cast oth eye	176
Although no worship, that is due alone	177
Not to the Carpenters, but Gods owne Sonne	178
Why should not Statua's bee as due to Paul	179
As to the Casars of the Capitoll?	180
How many Images of great Heires which	181
Had nothing but the Sin of being rich	182
Shine in our Temples? Kneeling always then	183
Wher when they were alive they'd scarce appeare,	184
Yet shall our Saviour have ne're a Tombe	185
Shall every Saint suffer John Baptists Doome	186
No Limbe of Mary stand? Shall wee forgett	187
Christs Crosse as soone as past our Alphabett?	188
Shall not ther Heads have Roome i'th windowes who	189
Founded our Church & our Relligion too?	190
Wee know that God's a Spirit wee confesse	191
Thoughts cannot comprehend his Name, much lesse	192
Can a small Glasse his Nature, but since hee	193
Vouchsaf'd to put on our Humanitie	194
Why may not wee only to put's in mind	195
Of's God head, have his manhood thus enshrin'd	196
Is our Kings Person 'lesse esteem'd because	197
Wee read him in his Coynes as wellas Lawes?	198
Doe what wee can whither wee thinke or ...	199
All Gods Expression will be weake & f...	200
But Spots in Globes must not bee blotted...	201
That cannot show the worlds magnifi...	202

Nor is it fitt wee should ye skill confraul...	203
Because no Artist ever drew ye Soule,	204
The Scriptures rayes contracted in a Gla...	205
Like SunBeams doe with greater vigor...	206
The cloudie misteries of the Gospell here	207
Transparent as ther Christall doe appea...	208
Tis not to see things darkly through a Gla...	209
Here wee may see our Saviour Face to Face	210
And whereas Feasts come seldome heres espie...	211
A Constant Christmasse, Easter, Whitsontide	212
Looke in the Booke of Martirs & you'le see	213
More by the Pictures then the Historie	214
That Price for Things in Colours oft wee give	215
Which wee'ld not take to have them when they live	216
Such power ther is in Painting that it makes	217
A loving Simpathie 'twixt Men & Snakes	218
Words passe away & soone as heard are gone	219
Wee read in Books what here wee dwell upon	220
Thus then ther's noe more fault in Imagerie	221
Both Edifie, what is in letters ther	222
Is written in plainer HeiroGlyphicks here	223
Tis not a new Relligion wee have chose	224
But the same Body put in better Cloathes.	225

A Poem, In defence of the decent Ornaments of Christ Church Oxon, occasioned by a Banbury brother published in *Parnassus Biceps* by Abraham Wright 1656

You that prophane our windows with a tongue	1
Set like some clock on purpose to go wrong;	2
Who when you were at Service sigh'd, because	3
You heard the Organs music not the Dawes:	4
Pittying our solemn state, shaking the head	5
To see no ruines from the flore to the lead:	6
To whose pure nose our Cedar gave offence,	7
Crying it smelt of Papist's frankincense:	8
Who walking on our Marbles scoffing said	9
Whose bodies are under these Tombstones laid:	10
Counting our Tapers works of darkness; and	11
Choosing to see Priests in Blue-aprons stand	12
Rather than in rich Coapes which show the art	13
Of Sisera's prey embroidered in each part:	14
Then when you saw the Altars Basen said	15
Why's not the Ewer on the Cupboards head,	16
Thinking our very Bibles too prophane,	17
'Cause you ne'er bought such Covers in <i>Ducklane</i> .	18
Loathing all decency, as if you'd have	19
Altars as foul and homely as a Grave.	20
Had you one spark of reason, you would find	21
Yourselves like Idols to have eyes yet blind.	22
Tis only some base niggard Heresie	23
To think Religion loves deformity.	24
Glory did never yet make God the less,	25
Neither can beauty defile holiness.	26
What's more magnificent than Heaven? Yet where	27
Is there more love and piety than there.	28
My heart doth wish (wer't possible) to see	29
<i>Pauls</i> built with pretious stones and porphery:	30
To have our Halls and Galleries outshine	31
Alters in beauty, is to deck our swine	32
With Orient Pearl, whilst the deserving Quire	33
Of God and Angels wallow in the mire:	34
Our decent Copes only distinction keep	35
That you may know the Shepherd from the sheep,	36
As gaudy letters in the Rubrick Show	37
How you may holy days from lay days know:	38

Remember <i>Aaron's</i> Robes and you will say	39
Ladies at Masques are not so rich as they.	40
Then areth Priests words like thunderclaps when he	41
Is lightening like rayed round with Majesty.	42
May every Temple shine like those of Nile,	43
And still be free from rat or Crocodile.	44
But you will urge both Priest and Church should be	45
The solemn patterns of humility.	46
Do not some boast of rags? Cynics deride	47
The pomp of Kings but with a greater pride.	48
Meekness consists not in the clothes but heart,	49
Nature may be vainglorious well as art;	50
We may as lowly before God appear	51
Drest with a glorious pearl as with a tear;	52
In his high presence where the Stars and Sun	53
Do but Eclipse there's no ambition.	54
You dare admit gay paint upon a wall,	55
Why then in glass that hold Apocriphal?	56
Our bodies Temples are: look in the eye	57
The Window, and you needs must pictures spy;	58
<i>Moses</i> and <i>Aaron</i> and the Kings arms are	59
Daubed in the Church when you the Warden were.	60
Yet you ne'er find for Papist: shall we say	61
<i>Banbury</i> is turned <i>Rome</i> , because we may	62
See the holy Lamb and Christopher? Nay more	63
The Alter stone set at the Tavern door?	64
Why can't the Ox then in the nativity	65
Be imaged forth, but Papists Bulls are nigh?	66
Our pictures to no other end are made	67
Then is your Time and sith your death and spade;	68
To us they're but mementoes, which present,	69
Christ best, except his Word and Sacrement.	70
If 'twere a sin to set up Imagry,	71
To get a Child were flat Idolary.	72
The models of our buildings would be thus	73
Directions to our houses, ruines to us.	74
Hath not each creature which hath daily birth	75
Something which resembles heaven or earth?	76
Suppose some ignorant Heathen once did bow	77
To Images, may we not see them now?	78
Should we love darkness and abhor the Sun	79

'Cause Persians gave it adoration?	80
And plant no Orchards, because apples first	81
Made <i>Adam</i> and his lineall race accurst?	82
Though wine for <i>Bacchus</i> , bread for <i>Ceres</i> went,	83
Yet both are now used in the Sacrement.	84
What then if these were popish relics? Few	85
Windowes are elsewhere old but these are new,	86
And so exceed the former, that the face	87
Of those come short of the outside of our glass;	88
Colours are here mix'd so, that Rainbows be	89
(Compared) but clouds without variety.	90
Art here is Natures envy: this is he,	91
Not <i>Paracelsus</i> , that by Chymistry	92
Can make a man from ashes, if not dust,	93
Producing off-springs of his mind not lust.	94
See how he makes his maker, and doth draw	95
All that is meant ith' Gospel, or ith' Law:	96
Looking upon the Resurrection	97
Me thoughts I saw the blessed vision,	98
Where not his face is merely drawn but mind,	99
Which not with paint but oil of gladness shind:	100
But when I viewed the next pane, where we have	101
The God of life transported to his grave,	102
Light then is dark, all things so dull and dead;	103
As if that part of the window had been lead.	104
<i>Jonas</i> his whale did so mens eyes befool	105
That they'd have begd him for th' Anatomy School.	106
That he saw Ships at <i>Oxford</i> one did swear,	107
Though <i>Isis</i> yet will Barges hardly bear.	108
Another soon as he the trees espied	109
Thought them i'th Garden on the other side.	110
See in what state (though on an Asse) Christ went,	111
This shows more glorious than the Parliament.	112
Then in what awe <i>Moses</i> his rod doth keep	113
The seas, as if a frost had glaz'd the deep;	114
The raging waves are to themselves a bound;	115
Some cry help help or horse and man are drowned.	116
Shadows do every where for substance passé,	117
You'd think the sands were in a hour-glass.	118
You that do live with Chirurgeons, have you seen	119
A spring of blood forst from a swelling vein?	120

So from a touch of <i>Moses</i> rod doth jump	121
A Chataract, the rock is made a pump:	122
At sight of whose o'erflowings many get	123
Themselves away for fear of being wet.	124
Have you beheld a sprightfull Lady stand	125
To have her frame drawn by a painters hand?	126
Such lively look and presence, such a dress	127
King <i>Pharoahs</i> Daughters Image doth express,	128
Look well upon her Gown and you will swear	129
The needle not the pencil hath been there:	130
At sight of her some gallants do dispute	131
Whether ith' Church 'tis lawful to salute.	132
Next <i>Jacob</i> kneeling, where his kids-skins such	133
As it may well cosen old <i>Isaacs</i> touch:	134
A Shepherd seeing how thorns went round about	135
<i>Abrahams</i> ram, would needs have helpt it out.	136
Behold the Dove descending to inspire	137
The Apostles heads with cloven tongues of fire,	138
And in a superficies there you'll see	139
The gross dimentions of profundity:	140
'Tis hard to judge which is best built and higher	141
The arch-roof in the window or the Quire.	142
All beasts as in the Ark are lively done,	143
Nay you may see the shadow of the Sun.	144
Upon a landscape if you look a while	145
You'll think the prospect at least forty mile.	146
There's none needs now go travel, we may see	147
At home <i>Jerusalem</i> and <i>Ninevy</i> ;	148
And <i>Sodom</i> now in flames: one glance will dart	149
Farther than Lynce with <i>Galilaus</i> art.	150
Seeing <i>Eliahs</i> Chariot, we fear	151
There is some fiery prodigy in the aire.	152
When Christ to purge his Temple holds his whip	153
How nimbly hucksters with their baskets skip.	154
St <i>Peter's</i> fishes are so lively wrought,	155
Some cheapen them and ask when they were caught.	156
Here's motion painted too: Chariots so fast	157
Run, that they're never gone though always past.	158
The Angels with their Lutes are done so true,	159
We do not only look but hearken too,	160
As if their sounds were painted: thus the wit	161

Of the pencil hath drawn more than there can sit.	162
Thus as (in Archimedes sphere) you may	163
In a small glass the universe survey:	164
Such various shapes are too ith' Imagry	165
As age and sex may their own features see.	166
But if the window cannot show your face	167
Look under feet the Marble is your glass,	168
Which too far more than Ornament is there	169
The stones may learn your eyes to shed a tear:	170
Yet though their lively shadows delude sence	171
They never work upon the conscience;	172
They cannot make us kneel; we are not such	173
As think there's balsam in their kiss or touch,	174
That were gross superstition we know;	175
There is no more power in them than the Pope's toe.	176
The Saints themselves for us can do no good,	177
Muchless their pictures drawn in glass and wood,	178
They cannot seal, but since they signify	179
They may be worthy of a cast oth' eye,	180
Although no worship: that is due alone	181
Not to the Carpenters but God's own Son:	182
Obedience to blocks deserves the rod;	183
The Lord may well be then a jealous God.	184
Why should not Statues now be due to <i>Paul</i> ,	185
As to the <i>Cesars</i> of the Capital.	186
How many Images of great heirs, which	187
Had nothing but the sin of being rich,	188
Shine in our Temples? Kneeling always there	189
Where when they were alive they'd scarce appear.	190
Yet shall Christs Sepulcher have ne'er a Tomb?	191
Shall every Saint suffer <i>John Baptist's</i> doom?	192
No limb of <i>Mary</i> stand? Must we forget	193
Christs cross as soon as past the Alphabet?	194
Shall not their heads have room in the window who	195
Founded our Church and our Religion too?	196
We know that God's a Spirit, we confess	197
Thoughts cannot comprehend his name, muchless	198
Can a small glass his nature: but since he	199
Vouchsaf'd to suffer his humanity,	200
Why may not we (only to puts in mind	201
Of his Godhead) have his manhood thus enshrind?	202

Is our Kings person less esteem'd because	203
We read him in our Coynes as well as Laws?	204
Do what we can, whether we think or paint,	205
All Gods expressions are but weak and faint.	206
Yet spots in Globes must not be blotted thence	207
That cannot show the world's magnificence.	208
Nor is it fit we should the skill control	209
Because the Artist cannot draw the soul.	210
Cease then your railings and your dull complaints;	211
To pull down Galleries and set up Saints	212
Is no impiety: now we may well	213
Say that our Church is truly visible:	214
Those that before our glass scaffolds prefer,	215
Would turn our Temple to a theatre.	216
Windows are Pulpits now; though unlearned, one	217
May read this Bibles new Edition.	218
Instead of here and there a verse adorn'd	219
Round with a lace of paint, fir to be scorn'd	220
Even by vulgar eyes, each pane presents	221
Whole chapters with both comment and contents,	222
The cloudy mysteries of the Gospel here	223
Transparent as the Christal do appear.	224
Tis not to see things darkly through a glass,	225
Here you may see our Saviour face to face.	226
And whereas Feasts come seldom, here's descried	227
A constant Christmas, Easter, Whitsontide.	228
Let the deaf hither come; no matter though	229
Faiths sence be lost, we a new way can show:	230
Here we can teach them to believe by the eye;	231
These silenced ministers do edify:	232
The Scriptures rayes contracted in a Glass	233
Like Emblems do with greater virtue pass.	234
Look in the book of Martyrs and you'll see	235
More by the Pictures than the History.	236
That price for things in colours oft we give	237
Which wee'd not take to have them while they live.	238
Such is he power of painting that it makes	239
A loving sympathy twixt men and snakes.	240
Hence then <i>Pauls</i> doctrin may seem more divine,	241
As Amber through a Glass doth clearer shine.	242
Words pass away, as soon as heard are gone;	243

We read in books what here we dwell upon,	244
Thus then there's no more fault in Imagry	245
Than there is in the Practise of piety,	246
Both edifie: what is in letters there	247
Is writ in plainer Hieroglyphics here.	248
Tis not a new Religion we have chose;	249
Tis the same body but in better clothes.	250
You'll say they make us gaze when we should pray	251
And that our thoughts do on the figures stray:	252
If so, you may conclude us beasts, what they	253
Have for their object is to us the way.	254
Did any ere use prospectives to see	255
No farther than the Glass: or can there be	256
Such lazy travellers, so given to sin,	257
As that they'll take their dwelling at the Inn.	258
A Christian's sight rests in Divinity,	259
Signs are but spectacles to help faiths eye,	260
God is the Centre: dwelling on these words,	261
My muse a Sabbath to my brain affords.	262
If their nice wits more solemn proof exact,	263
Know this was meant a Poem not a Tract.	264

On Christ Church Window and Magdalen College Wall J. Mennis 1656

Yee men of <i>Galilee</i> why gaze yee so	1
On <i>Maudlins</i> necessary print, as though	2
T'had bin enough for that pure virgin's sonne	3
That was incarnate, dyed, & rose, to have done	4
Those heavenly acts, that ransom'd al from hell	5
And yet no visible effigies tell	6
The eye, the manner how. Ye misconceive	7
Who think these sacred mysteryes must leave	8
Impression onely in the soul; how then	9
Shall those that bear more shape than mind of men,	10
(Unlesse their outward sense informe them) know	11
What accidents their Saviour long ago	12
Sustain'd? each wise man sees 'tis not the fate	13
Of every idiot to be literate.	14
And who can then forbid (ye Lay) to look	15
And read those things without or line or book.	16
Besides (if modestye may judge) what ist	17
But a supply to each Evangelist?	18
Long may the learned study, peace and scratch	19
Before the forme of th' mainger or the cratch	20
Wherein Babe Christ was layd be understood.	21
Each bungling joyner now may ken what wood	22
The stall was made of where the long eared steed	23
And his associate Oxe did stand and feed.	24
Each practis'd oastler knows their meat, can say	25
There is their provender, this is their hay.	26
Yee now may learne the naked shepherds hew	27
The stripling boy, and him it'h cap of blew,	28
As perfectly as it had seene the clownes	29
Each day a sunning on the jewish downes;	30
'Tis strange the dogg's not there, perhaps the Curr	31
Was left behind, for feare of noise or stirre:	32
But view the venerable face whereon	33
The horne and candle cast reflection,	34
Observe it well if ere you chance to meet	35
In paradise, you'le know't as soon as see't,	36
Tis reverent <i>Iosephs</i> portraiture, see how	37
The very image seemes to cringe and bow,	38
Marke well his beard, his eyes, his nose, if ought	39

Be mist, tis yours, and not the painters fault.	40
Then lead your eyes unto the beauteous one	41
Who nere knew man, yet mother to a sonne.	42
Doth not her face more fully speake her heart	43
And joy, than text or comment can impart?	44
But oh how little like her selfe when shee	45
Whose upcast, downe cast lookes, behold the tree?	46
That fatall tree whereon the Lord of breath	47
Expos'd himselfe to the' tyranny of death;	48
Was ever sorrow so set forth? and yet	49
To make the quire of heavinessse compleat,	50
The lov'd disciple bears his part, and so	51
Doth that brave lasse that clips the Crosse below.	52
Consult allauthors, English Greek & Lattin,	53
You nere saw truer greife or finer satin.	54
Foule fall the bird whose undiscerning mute	55
Presumes to turpifye so rich a suite;	56
T'was very strange they durst so boldly greeve	57
When those untutor'd hacksters of the Shreeve	58
Close by sat armed Cap-a-pee with speares,	59
And swords, and glittering helmets, or'e their eares	60
Bestriding fiery steeds so markt so made	61
<i>Bucephalus</i> himselfe was but a jade	62
Compar'd to these, why? who would be but vext	63
To see such palfreys here, and none it'h text?	64
Next let your eyes and thoughts be fixt upon	65
The sad-sad story of the passion;	66
See how from side, for feet, from hands as yet	67
The crimson blood trills down, you'l sweare twere wet;	68
Were <i>Thomas</i> here himselfe, he would not linger	69
But sooner trust his eyes then erst his finger.	70
Mark how death's sable cloud doth over-spread	71
His lips his cheeks, his eyes, his sacred head.	72
Behold death drawn to th'life, as if that hee	73
Thus wrackt and stretch't upon th' accursed tree,	74
Had been of purpose nayld to th' crosse to try	75
The Painters cunning hand, more than to dye.	76
He left him dead, but twas not in the power	77
Of grave, or hell to keep him, there one houre	78
Beyond his own determination.	79
Three dayes are past, and <i>Jonah's</i> type is done	80

He walkes, and in full glory leaps from tombe:	81
As <i>Lazarus</i> from th' earths insatiate wombe,	82
But not to dye againe: meane while the guard	83
Who vigilantly slept, soon as they heard	84
Deaths prisoner, and their's so strangely rise	85
Start up with frightened hearts and gastly eyes.	86
They stare and muse, and sweare, the heardsmen talke	87
Strange things, but nere till now saw dead men walke:	88
Do but take notice how the rascals look	89
As if some prodigie had thunderstrook	90
The villaines hearts, or some strange power had showne	91
<i>Medusae's</i> head, and turnd them all to stone.	92
Sure small perswasion would have made the Elves	93
For feare of further paines to hang themselves:	94
And blame them not, the Lord was now calcin'd	95
Bright as the Sun, his body so refin'd	96
That not the sawcinesse of mortall eye	97
Could stare upon such lustre and not dye.	98
His glorifi'd humanity can stay	99
No more on earth, heaven calls, he must away;	100
Yet ere he part hee'le take his leave, th'eleven,	101
Attend, and see him ravisht into heaven.	102
Their eyes (until an interposing cloud	103
Did interdict accesse of sight, and shrowd	104
His godlike countenance from mortall ken)	105
Still waite upon th'ascending Lord; but when	106
Distance had snatcht him from their view, they lift	107
Their hands to th' skie, as if they made some shift	108
To draw him down againe, such was their love	109
Theile scarce assent to his ascent above.	110
Where once more, note, the text supplied which tells	111
Th'Apostles were spectators and none else	112
But count byth' pole you'l find th' eleven increast	113
Their troops amount to five or sixe at least.	114
Were <i>Luke</i> alive, hee'd thank the painters wit,	115
Who saw his oversight and mended it.	116
Let's yield to reason then, let him that lists	117
Dispute the number of th' Evangelists;	118
If Judgement ever please this thing to lift	119
Or <i>Greenbury</i> or none must be the fift	120
I've done, but first Ile pray, hayle holy cloth	121

And live in spight of rottennesse or moth.	122
Nor time nor vermine ere shall dare to be	123
Corruptors of so much Divinitie;	124
But men of <i>Galilee</i> why do ye gaze,	125
On that which may delight, but not amaze?	126
That's left for us; let any wise man bend	127
His eyes towards our orientall end	128
Hee'le blesse himselfe indeed, grow wise; withall	129
Approaching take the window for a wall	130
And then conclude that <i>Wadehams</i> perspective	131
Nor <i>Lincolnes</i> stately types can long survive;	132
They'le break for envie (spight of wise) to find	133
Us to transcend themselves so farre behind;	134
But Ile not prayse our own, 'tis far more fit	135
To leave the talke to some fine Maud'lin wit,	136
Who may enroule in some well languish't staine	137
As we their walls, so they our lights againe	138
Only I feare they will, (least we surpasses)	139
Pull down their hall to build up Eastern glass.	140

On the Imperfection of Christ Church Buildings William Cartwright 1611-43

Arise, thou sacred heap, and show a frame	1
Perfect at last and glorious as thy name.	2
Space and torn majesty, as yet, are all	3
Thou hast; we view thy cradle, as thy fall.	4
Our dwelling lies half desert; the whole space	5
Unmeted and unbounded, bears the face	6
Of the first age's fields and we, as they	7
That stand on hills, have prospect every way.	8
Like Theseus' son, curst by mistake, the frame,	9
Scattered and torn, hath parts without a name,	10
Which in a landskip some mischance, not meant,	11
As dropping of the sponge would represent;	12
And, if no succour comes, the time's not far	13
When 'twill be thought no college but a quar.	14
Send then Amphion to these Thebes, O Fates!	15
We've here as many breaches, though not gates.	16
When any stranger comes, 'tis shewn by us,	17
As once the face was of Antigonus,	18
With an half visage only, so that all	19
We boast is but a kitchen or an hall.	20
Men thence admire, but help not; 't hath the luck	21
Of heathen places that were thunder-struck,	22
To be adorned, not touched: though the mind and will	23
Be in the pale, the purse is pagan still.	24
Alas! th' are towers that thunder do provoke,	25
We ne'er had height or glory for a stroke.	26
Time and King Henry, too, did spare us; we	27
Stood in those days both scythe and sceptre free.	28
Our ruins then were licenced and we were	29
Passed by untouched, that hand was open here.	30
Bless we our throne then! That which did avoid	31
The fury of those times seems yet destroyed.	32
So this, breathed on by no full influence	33
Hath hung e'er since unminded in suspense,	34
As doubtful whether 't should escheated be	35
To ruin, or redeemed to majesty.	36
But great intents stop seconds, and we owe	37
To larger wants that bounty is so slow.	38
A lordship here, like Curtius, might be cast	39

Into one hole and yet not seen at last.	40
Two sacred things were thought (by judging souls)	41
Beyond the kingdom's power, Chtist Church and Paul's,	42
Till by a light from Heaven shown, the one	43
Did gain his second renovation,	44
And some good star, ere long, we do not fear,	45
Will guide the wise to offer some gifts here.	46
But ruins yet stand ruins, as if none	47
Durst be so good, as first to cast a stone.	48
Alas! we ask not prodigies: we'd boast	49
Had we but what is at one horse-race lost;	50
Nor is our house (as Nature in the fall	51
Is thought by some) void and bereft of all	52
But what's new given; unto ourselves we owe	53
That skulls are not our Church's pavement now;	54
That that's made yet good way; that to his cup	55
And table Christ may come and not ride up;	56
That no one stumbling fears a worse event,	57
Nor, when he bows, falls lower than he meant;	58
That now our windows may for doctrine pass,	59
And we (as Paul) see mysteries in a glass;	60
That something elsewhere is performed, whereby	61
'Tis seen we can adorn, though not supply.	62
But if to all great buildings, as to Troy,	63
A god must needs be sent, and we enjoy	64
No help but miracle, if so it stand	65
Decreed by Heaven, that the same gracious hand	66
That perfected our statutes, must be sent	67
To finished Christ Church too, we are content;	68
Knowing that He who in the Mount did give	69
Those laws by which his people were to live,	70
If they had needed them, as we do now,	71
Would have bestowed the stone for tables too.	72

Appendix B

SEM-WDS

Price

Sample	Date of Glass	Colour	Window
CCOX44	Price 1696	Greenish	Green/grey paint
CCOX57	Price 1696	Pale Green	Yellow/flesh paint
CCOX106	Price 1696		Wolsey's Crest
CCOX107	Price 1696		
CCOX110	Price 1696		Birch Family
CCOX111	Price 1696		Nativity
CCOX113	Price 1696	Greenish	Price
CCOX116	Price 1696	Greenish	Price - red scroll
CCOX117	Price 1696	Greenish	Price - red scroll
CCOX118	Price 1696	Greenish	Price - swan
CCOX119	Price 1696	Greenish	Price - name plate
CCOX120	Price 1696	Greenish	Price - architecture
CCOX126	Price 1696		Foot
CCOX127	Price 1696		Feet
CCOX129	Price 1696		Star from Nativity
CCOX122	Price/Oliver?		Beardy Guy
CCOX12	Price? 1696?	Colourless	Yellow/Black paint
CCOX50	Price? 1696?	Greenish	Yellow/grey paint
CCOX51	Price? 1696?	Pale Green	Green paint
CCOX56	Price? 1696?	Pale Green	Yellow/flesh paint
CCOX07	Unknown	Green/Colourless	Dark painted surface
CCOX13	Unknown	Colourless	Dark painted surface
CCOX35	Unknown	Grey	Painted
CCOX38	Unknown	Greenish	Dark purple paint
CCOX54	Unknown	Pale Green	Dark paint
CCOX59	Unknown	Pale Green	Dark Paint

CCOX61	Unknown	Pale Green	Dark Paint
CCOX62	Unknown	Pale Green	Dark Paint
CCOX115	Unknown		Fleur de Lis
CCOX45	V.L. 1640	Greenish	Yellow/green paint
CCOX15	V.L.? 1640?	Grey	
CCOX58	V.L.? 1640?	Pale Green	Dark Paint
CCOX60	V.L.? 1640?	Pale Green	Dark Paint
CCOX22	1640/1696?	Grey	Heraldry

Sample	Na2O	SiO2	MgO	Al2O3	TiO2	P2O5	K2O	CaO	SO3	Cl	Cr2O3	Fe2O3
CCOX44	0.83	60.22	1.79	1.96	0.17	2.09	5.80	23.08	0.28	0.10	0.02	0.98
CCOX57	0.94	59.38	1.92	2.25	0.14	0.67	6.11	23.65	0.39	0.11	0.00	1.27
CCOX106	0.95	58.87	1.90	2.01	0.17	2.15	6.50	23.62	0.32	0.12	0.05	1.06
CCOX107	0.87	59.64	1.81	2.03	0.16	2.23	6.06	23.47	0.33	0.08	0.00	0.99
CCOX110	1.01	57.77	2.07	2.23	0.18	2.41	6.69	23.41	0.27	0.12	0.00	1.13
CCOX111	0.85	60.23	1.78	1.97	0.17	2.13	5.91	23.12	0.40	0.10	0.03	0.99
CCOX113	0.94	59.68	1.98	2.28	0.16	2.28	5.78	24.16	0.54	0.11	0.00	1.27
CCOX116	0.95	60.78	1.99	2.13	0.16	2.21	6.40	22.72	0.48	0.11	0.00	1.17
CCOX117	0.92	59.48	1.99	2.27	0.16	2.30	5.86	23.93	0.56	0.10	0.00	1.28
CCOX118	0.95	60.17	2.04	2.21	0.16	2.21	6.08	23.28	0.45	0.11	0.00	1.27
CCOX119	0.94	59.44	1.98	2.26	0.17	2.31	5.74	24.10	0.51	0.10	0.00	1.24
CCOX120	1.02	59.07	2.15	2.27	0.18	2.48	6.60	23.25	0.38	0.10	0.00	1.32
CCOX126	0.93	59.83	1.91	2.01	0.14	2.18	6.20	22.81	0.36	0.09	0.02	1.00
CCOX127	0.92	58.10	1.93	2.15	0.15	2.22	6.45	23.89	0.38	0.10	0.00	1.04
CCOX129	0.93	57.99	1.87	2.18	0.13	2.29	5.92	24.19	0.39	0.12	0.02	1.03
CCOX122	0.89	59.55	1.84	2.16	0.16	2.23	5.96	23.40	0.27	0.08	0.00	1.01
CCOX12	0.94	58.98	1.92	2.16	0.14	0.61	6.28	23.60	0.43	0.12	0.00	1.21
CCOX50	1.05	58.02	2.03	2.28	0.18	2.55	6.73	22.84	0.31	0.13	0.02	1.09
CCOX51	1.00	58.79	2.04	2.28	0.12	2.40	5.81	22.91	0.31	0.10	0.02	1.17
CCOX56	0.89	60.02	1.84	1.94	0.13	2.16	6.12	22.51	0.33	0.10	0.01	1.03
CCOX07	1.00	57.88	2.00	2.27	0.17	2.39	6.95	23.40	0.36	0.10	0.03	1.18

CCOX13	0.95	59.11	1.84	2.11	0.16	2.23	6.37	23.14	0.31	0.10	0.03	1.07
CCOX35	0.90	58.63	1.89	2.10	0.15	2.18	6.32	23.65	0.38	0.09	0.01	1.07
CCOX38	1.02	57.99	2.06	2.25	0.16	2.43	6.89	23.10	0.32	0.11	0.02	1.13
CCOX54	0.95	57.87	1.93	2.20	0.15	2.27	5.95	24.16	0.53	0.12	0.02	0.99
CCOX59	0.90	57.88	1.94	2.19	0.15	2.21	5.88	24.40	0.46	0.11	0.00	1.06
CCOX61	1.04	58.33	2.07	2.35	0.20	2.45	5.98	23.56	0.29	0.12	0.05	1.27
CCOX62	0.99	57.22	1.97	2.39	0.16	0.79	6.89	23.61	0.36	0.10	0.00	1.34
CCOX115	1.02	59.47	2.03	2.29	0.19	2.34	5.77	23.00	0.23	0.10	0.01	1.28
CCOX45	1.01	59.27	2.12	2.31	0.18	2.47	6.76	23.18	0.34	0.11	0.00	1.34
CCOX15	0.92	61.69	1.92	1.98	0.15	2.22	5.97	22.34	0.39	0.11	0.01	1.13
CCOX58	0.93	59.04	1.95	2.23	0.16	2.31	5.72	23.87	0.52	0.10	0.00	1.22
CCOX60	0.91	58.62	1.89	2.30	0.14	0.69	6.02	24.63	0.48	0.11	0.00	1.23
CCOX22	1.01	59.03	2.06	2.42	0.16	0.64	6.08	23.57	0.35	0.10	0.00	1.38

Sample	MnO	CoO	NiO	CuO	ZnO	SrO	SnO	Sb2O5	BaO	PbO	Total
CCOX44	0.13	0.00	0.00	0.02	0.00		0.00	0.00	0.03	0.01	97.49
CCOX57	0.14	0.01	0.00	0.00	0.02	0.00	0.01	0.49	0.04	0.04	97.58
CCOX106	0.04	0.02	0.01	0.05	0.01		0.01	0.00	0.05	0.01	97.90
CCOX107	0.08	0.09	0.06	0.10	0.06		0.01	0.00	0.05	0.04	98.14
CCOX110	0.16	0.10	0.05	0.06	0.11		0.02	0.00	0.06	0.11	97.93
CCOX111	0.11	0.05	0.07	0.05	0.01		0.06	0.00	0.01	0.03	98.03
CCOX113	0.17	0.00	0.01	0.02	0.04	0.00	0.00	0.12	0.04	0.00	99.58
CCOX116	0.17	0.00	0.00	0.01	0.04	0.00	0.00	0.12	0.02	0.01	99.47
CCOX117	0.14	0.00	0.00	0.00	0.04	0.00	0.00	0.11	0.02	0.01	99.17
CCOX118	0.14	0.01	0.00	0.02	0.00	0.00	0.00	0.13	0.01	0.04	99.28
CCOX119	0.17	0.00	0.00	0.00	0.02	0.00	0.00	0.12	0.02	0.00	99.12
CCOX120	0.18	0.00	0.00	0.01	0.00	0.00	0.00	0.12	0.02	0.00	99.15
CCOX126	0.14	0.06	0.05	0.06	0.16		0.00	0.00	0.03	0.03	97.99
CCOX127	0.19	0.06	0.05	0.08	0.19		0.04	0.00	0.06	0.05	98.05
CCOX129	0.09	0.01	0.00	0.05	0.06		0.01	0.00	0.00	0.01	97.31
CCOX122	0.12	0.01	0.02	0.02	0.11		0.07	0.00	0.03	0.08	98.02

CCOX12	0.10	0.00	0.00	0.02	0.03	0.00	0.01	0.54	0.04	0.04	97.17
CCOX50	0.17	0.07	0.05	0.10	0.07		0.04	0.00	0.09	0.06	97.87
CCOX51	0.20	0.03	0.00	0.00	0.02		0.04	0.00	0.06	0.00	97.30
CCOX56	0.08	0.02	0.00	0.03	0.11		0.00	0.00	0.05	0.08	97.42
CCOX07	0.13	0.00	0.01	0.03	0.21		0.00	0.00	0.05	0.02	98.16
CCOX13	0.14	0.01	0.07	0.10	0.17		0.02	0.00	0.10	0.04	98.06
CCOX35	0.10	0.07	0.07	0.06	0.08		0.00	0.00	0.01	0.06	97.82
CCOX38	0.15	0.02	0.05	0.03	0.00		0.01	0.00	0.04	0.08	97.84
CCOX54	0.11	0.02	0.03	0.06	0.07		0.02	0.00	0.08	0.02	97.55
CCOX59	0.17	0.00	0.07	0.00	0.10		0.00	0.00	0.01	0.06	97.57
CCOX61	0.19	0.03	0.03	0.05	0.11		0.00	0.00	0.04	0.05	98.24
CCOX62	0.14	0.00	0.00	0.01	0.00	0.00	0.00	0.46	0.07	0.02	96.52
CCOX115	0.13	0.02	0.01	0.08	0.05		0.03	0.00	0.07	0.02	98.11
CCOX45	0.17	0.00	0.00	0.02	0.00	0.00	0.00	0.14	0.01	0.03	99.46
CCOX15	0.09	0.00	0.00	0.00	0.01	0.00	0.00	0.12	0.01	0.01	99.07
CCOX58	0.15	0.00	0.00	0.02	0.01	0.00	0.00	0.13	0.02	0.02	98.40
CCOX60	0.16	0.00	0.00	0.02	0.03	0.00	0.02	0.46	0.05	0.00	97.76
CCOX22	0.20	0.01	0.00	0.00	0.05	0.00	0.01	0.52	0.08	0.00	97.67

SEM-WDS

Victorian

Group	Sample	Date of Glass	Colour	Window
2	CCOX25	Victorian	Flashed Red	
2	CCOX27	Victorian	Flashed Red	
2	CCOX31	Victorian	Flashed Red	
2	CCOX103	Victorian		Victorian
2	CCOX125	Victorian	purple	robe/drapery
2	CCOX128	Victorian	Flashed Red	Drapery/Clerical Clothes
2	CCOX01	Vic?	Colourless	Rising Sun
2	CCOX123	V.L.? 1640? Or Vic	light blue enameled black	
2	CCOX28	vic/later	Yellow/amber	
2	CCOX29	vic/later	Green	

Sample	Na2O	SiO2	MgO	Al2O3	TiO2	P2O5	K2O	CaO	SO3	Cl	Cr2O3	Fe2O3
CCOX25	12.86	68.29	0.07	0.79	0.05	0.06	1.18	11.22	0.27	0.15	0.00	0.21
CCOX27	12.73	68.03	0.07	0.80	0.08	0.07	1.24	11.28	0.25	0.15	0.01	0.18
CCOX31	11.83	70.08	0.17	1.33	0.05	0.02	0.46	13.15	0.43	0.10	0.00	0.42
CCOX103	12.14	67.90	0.28	1.34	0.12	0.06	0.36	13.10	0.40	0.10	0.03	1.05
CCOX125	10.00	68.06	0.10	1.22	0.12	0.06	3.84	10.80	0.38	0.12	0.00	0.53
CCOX128	11.69	69.22	0.15	1.31	0.02	0.03	0.47	13.05	0.33	0.08	0.00	0.34
CCOX01	11.45	68.99	0.25	1.55	0.11	0.02	0.32	13.08	0.49	0.05	0.05	0.97
CCOX123	5.66	66.72	0.08	1.01	0.09	0.06	12.91	2.78	0.20	0.17	0.01	0.22
CCOX28	11.11	64.35	0.11	3.75	0.19	0.02	0.15	10.80	0.35	0.03	0.00	1.89
CCOX29	14.18	63.27	0.13	1.97	0.10	0.04	1.65	9.60	0.52	0.47	0.04	1.75

Sample	MnO	CoO	NiO	CuO	ZnO	SrO	SnO	Sb2O5	BaO	PbO	Total
CCOX25	0.16	0.01	0.05	0.02	0.09		0.04	0.00	0.12	2.53	98.65
CCOX27	0.13	0.03	0.00	0.05	0.04		0.03	0.00	0.03	2.67	98.28
CCOX31	0.42	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.04	0.00	98.58
CCOX103	0.62	0.03	0.00	0.08	0.00		0.06	0.00	0.03	0.02	97.83
CCOX125	1.13	0.02	0.12	0.10	0.00		0.05	0.00	0.18	0.86	97.95
CCOX128	0.35	0.02	0.01	0.01	0.06		0.02	0.00	0.02	0.00	97.48
CCOX01	0.36	0.03	0.02	0.06	0.09		0.05	0.00	0.02	0.07	98.30
CCOX123	0.04	0.04	0.09	2.82	0.09		0.00	0.00	0.03	4.27	97.80
CCOX28	5.90	0.00	0.00	0.05	0.02	0.00	0.03	0.03	0.05	0.40	99.23
CCOX29	1.06	0.03	0.29	0.78	0.01	0.00	0.02	0.15	0.12	3.37	99.55

SEM-WDS**Van Linge**

Group	Sample	Date of Glass	Colour	Window
3	CCOX06	V.L. 1640	Colourless	Painted criss cross black lines
3	CCOX08	V.L. 1640	Colourless	Blue painted - Crizzled
3	CCOX09	V.L. 1640	Colourless	Blue/Purple painted - Crizzled
3	CCOX10	V.L. 1640	Colourless	Blue/Purple painted - Crizzled
3	CCOX11	V.L. 1640	Colourless	Blue/Purple paint
3	CCOX37	V.L. 1640	Greenish	Blue paint
3	CCOX42	V.L. 1640	Greenish	Blue/grey paint
3	CCOX43	V.L. 1640	Greenish	Green/grey paint
3	CCOX46	V.L. 1640	Greenish	Green/grey paint
3	CCOX47	V.L. 1640	Greenish	Yellow/green paint
3	CCOX48	V.L. 1641	Greenish	Green/grey paint
3	CCOX49	V.L. 1640	Greenish	Green/grey paint
3	CCOX52	V.L. 1640	Pale Green	Green/grey paint
3	CCOX55	V.L. 1640	Pale Green	Grey paint
3	CCOX63	V.L. 1640	Pale Green	Blue/Grey/Red paint
3	CCOX101	V.L. 1640 (w)	Colourless	Robert King Family
3	CCOX104	V.L. 1640 (w)	Colourless	Christ Disputing Drs
3	CCOX105	V.L. 1640 (w)	Colourless	Christ Disputing Drs
3	CCOX108	V.L. 1640 (w)	Colourless	Anatomy of Melancholy
3	CCOX109	V.L. 1640 (w)	Colourless	Thomas Family
3	CCOX17	V.L.? 1640?	Grey	corner piece?
3	CCOX18	V.L.? 1640?	Grey	
3	CCOX19	V.L.? 1640?	Grey	
3	CCOX34	V.L.? 1640?	Grey	
3	CCOX36	V.L.? 1640?	Grey	Painted
3	CCOX39	V.L.? 1640?	Green	Dark Grey paint

3	CCOX40	V.L.? 1640?	Greenish	Grey paint
3	CCOX41	V.L.? 1640?	Greenish	Grey paint
3	CCOX33	Unknown Blue	Dark Blue	
3	CCOX121	V.L.? 1640?	Dark Blue	
3	CCOX23	Victorian	Grey	Painted leaf - Grisaille
3	CCOX24	Victorian	Grey	Painted leaf - Grisaille
3	CCOX30	vic?	Flashed Dark Red	
3	CCOX32	vic?	Purple	
3	CCOX04	Unknown	Colourless	remnant white and black paint
3	CCOX14	Unknown	Colourless	Blue paint
3	CCOX16	Unknown	Grey	Black paint
3	CCOX20	Unknown	Grey	
3	CCOX21	Unknown	Grey	
3	CCOX53	Unknown	Pale Green	Dark paint
3	CCOX114	Unknown		Flower
3	CCOX124	Unknown	green enameled	scales/laurel wreath/heradic?

Sample	Na2O	SiO2	MgO	Al2O3	TiO2	P2O5	K2O	CaO	SO3	Cl	Cr2O3	Fe2O3
CCOX06	3.24	59.55	3.06	3.04	0.17	0.58	4.51	19.90	0.17	0.57	0.00	0.90
CCOX08	3.38	59.56	3.05	3.05	0.18	0.53	4.28	20.57	0.15	0.60	0.00	0.91
CCOX09	3.48	62.05	2.95	3.14	0.22	1.88	3.99	19.68	0.09	0.54	0.00	0.91
CCOX10	3.42	61.43	3.08	2.97	0.20	2.05	4.22	20.36	0.10	0.66	0.00	0.80
CCOX11	3.48	62.29	2.95	3.17	0.21	1.88	4.00	19.64	0.10	0.55	0.00	0.88
CCOX37	3.50	61.88	2.77	3.25	0.23	1.95	4.02	19.75	0.08	0.54	0.00	1.01
CCOX42	3.51	62.10	2.89	3.17	0.21	1.93	3.85	19.53	0.09	0.52	0.00	0.94
CCOX43	3.27	60.46	2.86	3.07	0.18	0.58	4.08	20.08	0.07	0.52	0.00	0.88
CCOX46	3.38	60.64	2.77	3.14	0.19	0.57	4.11	19.91	0.08	0.57	0.00	0.92
CCOX47	2.55	55.88	3.07	4.48	0.22	0.66	5.03	21.08	0.07	0.40	0.00	1.19
CCOX48	3.20	62.00	2.88	3.01	0.20	1.96	4.15	19.99	0.09	0.55	0.00	0.89
CCOX49	2.19	55.73	3.06	4.18	0.21	0.64	4.81	23.08	0.10	0.41	0.00	1.18
CCOX52	3.37	57.99	2.94	3.20	0.20	0.70	4.34	20.81	0.15	0.61	0.00	0.88

CCOX55	2.99	59.27	3.05	3.22	0.21	0.65	5.14	19.93	0.18	0.57	0.00	0.95
CCOX63	3.75	58.97	3.04	2.94	0.21	0.69	3.64	20.50	0.10	0.62	0.00	0.97
CCOX101	3.45	62.18	2.75	3.29	0.22	1.94	4.04	19.62	0.06	0.60	0.00	0.97
CCOX104	3.61	60.82	3.19	2.87	0.22	2.33	3.75	20.04	0.09	0.63	0.00	0.96
CCOX105	3.23	62.00	2.99	2.99	0.21	2.08	3.97	19.85	0.10	0.53	0.00	0.89
CCOX108	3.69	60.49	3.25	2.92	0.23	2.35	3.58	20.09	0.12	0.54	0.00	1.08
CCOX109	3.57	59.89	3.08	3.17	0.24	2.19	3.95	20.89	0.08	0.62	0.00	0.91
CCOX17	2.49	58.02	3.27	4.24	0.20	0.53	5.33	21.17	0.09	0.37	0.00	1.28
CCOX18	4.52	59.86	3.27	4.71	0.16	0.39	4.02	17.84	0.25	0.51	0.00	1.61
CCOX19	4.54	61.47	3.44	4.58	0.20	1.43	3.90	17.59	0.26	0.53	0.00	1.69
CCOX34	3.28	57.98	3.23	3.01	0.19	0.58	5.10	20.83	0.18	0.59	0.00	0.95
CCOX36	3.60	60.47	3.23	2.95	0.22	2.36	3.72	19.87	0.12	0.60	0.00	0.99
CCOX39	3.09	59.92	3.04	2.83	0.14	0.57	4.70	20.53	0.07	0.53	0.00	0.81
CCOX40	3.79	60.18	3.23	2.90	0.22	2.36	3.54	20.19	0.11	0.55	0.00	1.06
CCOX41	3.38	59.74	2.93	2.98	0.18	0.58	4.24	20.59	0.11	0.58	0.00	0.84
CCOX33	0.99	55.23	3.11	2.98	0.25	0.94	6.99	22.33	0.31	0.07	0.00	1.60
CCOX121	1.24	55.08	3.13	2.91	0.29	3.18	6.64	21.75	0.36	0.09	0.00	1.69
CCOX23	2.23	59.11	2.72	2.24	0.23	0.60	4.23	22.72	0.16	0.52	0.00	1.33
CCOX24	2.10	59.29	2.80	2.44	0.25	0.55	4.15	22.74	0.18	0.43	0.00	1.41
CCOX30	0.96	53.53	3.32	3.11	0.25	1.03	7.71	24.03	0.34	0.06	0.00	1.37
CCOX32	0.46	54.00	3.47	4.14	0.20	0.73	10.67	18.32	0.36	0.06	0.00	0.62
CCOX04	4.12	58.78	3.42	4.40	0.18	0.37	3.33	20.21	0.65	0.33	0.00	1.43
CCOX14	3.44	60.37	2.86	3.07	0.21	1.95	4.03	19.67	0.10	0.50	0.02	0.76
CCOX16	3.58	58.46	3.01	3.08	0.19	2.11	4.11	20.96	0.04	0.58	0.00	0.79
CCOX20	3.71	59.96	3.85	2.11	0.14	1.53	2.97	21.19	0.54	0.38	0.01	0.90
CCOX21	3.69	60.77	3.85	2.20	0.12	0.41	3.09	21.55	0.60	0.39	0.00	1.15
CCOX53	2.23	57.01	2.95	4.18	0.25	2.03	5.76	21.36	0.12	0.35	0.02	1.10
CCOX114	4.51	61.68	3.63	2.69	0.16	1.44	3.28	18.60	0.08	0.75	0.05	0.95
CCOX124	0.69	57.28	3.01	1.32	0.14	2.06	6.08	21.64	0.35	0.05	0.00	0.31

Sample	MnO	CoO	NiO	CuO	ZnO	SrO	SnO	Sb2O5	BaO	PbO	Total
CCOX06	0.80	0.01	0.04	0.00	0.02	0.00	0.01	0.41	0.21	0.03	97.22
CCOX08	0.76	0.00	0.00	0.01	0.02	0.00	0.01	0.39	0.21	0.02	97.68
CCOX09	0.64	0.00	0.00	0.01	0.00	0.00	0.03	0.09	0.17	0.04	99.91
CCOX10	0.71	0.01	0.00	0.00	0.00	0.00	0.00	0.09	0.17	0.02	100.29
CCOX11	0.69	0.00	0.00	0.00	0.02	0.00	0.04	0.07	0.16	0.00	100.13
CCOX37	0.68	0.00	0.00	0.00	0.02	0.00	0.00	0.09	0.20	0.00	99.97
CCOX42	0.66	0.00	0.00	0.01	0.01	0.00	0.05	0.08	0.19	0.02	99.76
CCOX43	0.73	0.00	0.00	0.01	0.02	0.00	0.02	0.33	0.19	0.02	97.37
CCOX46	0.69	0.00	0.00	0.01	0.00	0.00	0.02	0.33	0.19	0.01	97.53
CCOX47	0.57	0.01	0.00	0.00	0.02	0.00	0.00	0.36	0.21	0.02	95.82
CCOX48	0.63	0.01	0.01	0.00	0.04	0.00	0.00	0.10	0.19	0.00	96.70
CCOX49	0.55	0.00	0.00	0.01	0.05	0.00	0.02	0.35	0.21	0.00	96.78
CCOX52	0.75	0.00	0.00	0.00	0.00	0.00	0.01	0.30	0.23	0.02	96.50
CCOX55	0.90	0.02	0.00	0.00	0.00	0.00	0.01	0.42	0.19	0.00	97.70
CCOX63	0.83	0.02	0.00	0.00	0.02	0.00	0.00	0.28	0.22	0.04	96.84
CCOX101	0.68	0.00	0.00	0.01	0.03	0.00	0.00	0.08	0.17	0.03	100.12
CCOX104	0.81	0.00	0.00	0.01	0.00	0.00	0.00	0.09	0.22	0.03	99.67
CCOX105	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.20	0.02	99.90
CCOX108	0.84	0.00	0.01	0.00	0.01	0.00	0.00	0.08	0.22	0.06	99.56
CCOX109	0.73	0.00	0.02	0.01	0.00	0.00	0.00	0.08	0.21	0.02	99.66
CCOX17	0.65	0.00	0.00	0.00	0.03	0.00	0.00	0.47	0.21	0.02	98.37
CCOX18	0.13	0.00	0.00	0.00	0.02	0.00	0.01	0.33	0.04	0.01	97.68
CCOX19	0.13	0.01	0.01	0.01	0.03	0.00	0.00	0.08	0.03	0.02	95.41
CCOX34	0.97	0.02	0.00	0.01	0.01	0.00	0.01	0.43	0.19	0.03	97.59
CCOX36	0.89	0.01	0.00	0.00	0.00	0.00	0.00	0.08	0.23	0.04	95.78
CCOX39	0.77	0.00	0.00	0.01	0.01	0.00	0.01	0.39	0.19	0.03	97.64
CCOX40	0.87	0.00	0.01	0.00	0.00	0.00	0.00	0.08	0.23	0.07	99.39
CCOX41	0.72	0.00	0.00	0.01	0.03	0.00	0.00	0.34	0.20	0.00	97.45

CCOX33	0.62	0.34	0.10	0.04	0.00	0.00	0.01	0.59	0.07	0.00	96.57
CCOX121	0.71	0.34	0.12	0.04	0.01	0.00	0.00	0.13	0.10	0.02	97.83
CCOX23	0.83	0.01	0.01	0.02	0.02	0.00	0.01	0.38	0.16	0.00	97.53
CCOX24	0.77	0.05	0.02	0.01	0.05	0.00	0.00	0.39	0.14	0.00	97.77
CCOX30	0.71	0.02	0.00	0.02	0.00	0.00	0.01	0.60	0.13	0.02	97.22
CCOX32	2.85	0.02	0.02	0.00	0.04	0.00	0.01	0.79	0.74	0.02	97.52
CCOX04	0.12	0.00	0.00	0.01	0.01	0.00	0.02	0.28	0.09	0.00	97.75
CCOX14	0.61	0.02	0.00	0.05	0.04		0.07	0.00	0.17	0.04	97.91
CCOX16	0.73	0.05	0.02	0.09	0.00		0.01	0.00	0.21	0.03	98.02
CCOX20	0.07	0.09	0.05	0.04	0.00		0.02	0.00	0.04	0.03	97.58
CCOX21	0.11	0.00	0.00	0.00	0.03	0.00	0.01	0.28	0.03	0.02	98.30
CCOX53	0.48	0.04	0.05	0.06	0.00		0.05	0.00	0.27	0.03	98.28
CCOX114	0.05	0.03	0.04	0.04	0.02		0.02	0.00	0.11	0.03	98.03
CCOX124	0.95	0.00	0.03	1.80	0.10		0.03	0.00	0.16	2.20	98.20

SEM-WDS

Other

Group	Sample	Date of Glass	Colour	Window
4	CCOX102	Medieval		Medieval from Latin Chapel
4	CCOX02	Unknown	Colourless	
4	CCOX03	Unknown	Colourless	
4	CCOX05	Unknown	Colourless	

Sample	Na2O	SiO2	MgO	Al2O3	TiO2	P2O5	K2O	CaO	SO3	Cl	Cr2O3	Fe2O3
CCOX102	2.34	52.98	7.79	1.54	0.10	3.48	12.44	15.24	0.22	0.19	0.00	0.54
CCOX02	9.12	68.01	2.43	0.85	0.07	0.14	5.15	11.14	0.08	0.84	0.00	0.31
CCOX03	8.77	67.46	2.69	0.83	0.07	0.57	5.10	11.14	0.09	0.75	0.01	0.34
CCOX05	8.77	67.42	2.74	0.85	0.10	0.51	5.15	11.12	0.08	0.80	0.02	0.30

Sample	MnO	CoO	NiO	CuO	ZnO	SrO	SnO	Sb2O5	BaO	PbO	Total
CCOX102	1.07	0.08	0.06	0.09	0.10		0.06	0.00	0.17	0.05	98.59
CCOX02	0.08	0.00	0.00	0.00	0.00	0.00	0.02	0.43	0.00	0.04	98.71
CCOX03	0.07	0.10	0.00	0.03	0.04		0.03	0.00	0.00	0.06	98.00
CCOX05	0.08	0.04	0.03	0.08	0.07		0.00	0.00	0.03	0.15	98.16

LA-ICP-MS

Price

Sample	Li7	Be9	B11	Al27	Ca43	Ca44	Sc45	Ti47	V51	Cr53	Mn55	Fe57	Co59	Ni60	Cu63
CCOX 113	13.53	0.547	199.42	10965.41	173391.1	172671.7	2.039	775.83	21.9	15.61	1160.37	8306.15	4.39	16.42	92.86
CCOX 116	13.21	0.502	205.25	9932.7	162267.3	162380.1	2.061	736.97	20.84	15.35	924.6	7954.05	4.27	16.14	94.78
CCOX 117	13.04	0.569	197.06	11022.75	170485.6	171027.9	2.102	794.36	22.06	15.76	1196.24	8653.35	4.57	17.17	100.29
CCOX 118	12.55	0.579	214.36	10233.2	167069.8	166382.3	2.095	769.07	23.97	16.86	933.5	8582.99	4.48	16.48	98.84
CCOX 119	12.56	0.479	194.06	10914.67	171967.1	172242.9	2.103	787.88	22.11	15.76	1205.1	8680.71	4.55	17.05	97.1
CCOX 120	12.2	0.509	192.07	10764.34	166738.9	166168	2.253	856.07	23.17	17.28	1310.68	9272.25	4.89	17.49	99.89
CCOX 45	10.51	0.488	183.16	10779.88	163585.5	165667.7	2.279	882.55	22.75	17.91	1165.79	9231	4.65	17.76	99.98
CCOX 15	12.47	0.468	189.51	9364.53	159963	159664.2	1.94	715.77	19.54	14.45	847.83	7526.76	3.93	14.83	91.73
CCOX 58	11.85	0.485	169.16	10523.78	169656.3	170599.1	2.08	800.35	21.58	15.72	1174.37	8660	4.43	16.84	96.71

Sample	Zn66	Ga69	Ge72	As75	Rb85	Sr88	Y89	Zr90	Ag107	Sn118	Sb121	Cs133	Ba137	La139	Ce140
CCOX 113	253.68	6.96	1.81	6.79	81.22	582.69	7.06	106.38	0.863	24.37	0.71	1.15	477.55	11.24	20.65
CCOX 116	259.96	6.38	1.85	6.13	81.92	577.58	6.9	100.33	0.808	34.79	0.86	1.15	441.11	11.01	20.76
CCOX 117	284.08	7.02	1.99	7.36	89.94	612.4	7.96	117.59	0.95	27.24	0.78	1.27	507.65	12.34	22.07
CCOX 118	254.78	6.5	1.82	7.55	79.81	601.99	7.11	104.87	1.28	102.59	1.76	1.21	453.94	11.7	22.57
CCOX 119	271.36	6.95	1.96	7.02	86.31	604.84	7.72	114.86	0.931	26.72	0.79	1.28	512.69	12.36	22.46
CCOX 120	246.45	6.98	1.51	6.58	78.56	636.11	8.17	122.61	1	40.97	0.79	1.13	563.74	13.28	24.87
CCOX 45	250.04	6.84	1.64	7.13	81.98	624.9	8.36	130.96	1.09	46.61	0.84	1.22	545.3	13.3	24.31
CCOX 15	214.47	5.6	1.43	6.19	69.51	545.4	6.22	96.91	1.06	56.5	1.02	0.99	428.97	9.98	19.01
CCOX 58	253.73	6.37	2.02	7.58	86.41	605.16	7.63	119.38	0.882	26.2	0.68	1.2	507.31	11.91	21.92

Sample	Pr141	Nd146	Sm147	Eu153	Gd157	Tb159	Dy163	Ho165	Er166	Tm169	Yb172	Lu175	Pb208	Bi209	Th232	U238
CCOX 113	2.39	9.19	1.78	0.415	1.44	0.218	1.32	0.285	0.78	0.114	0.8	0.126	114.42	0.175	2.34	0.79
CCOX 116	2.36	9.17	1.78	0.393	1.36	0.222	1.26	0.262	0.73	0.108	0.81	0.122	148.2	0.163	2.34	0.8
CCOX 117	2.56	10.5	1.98	0.454	1.61	0.264	1.64	0.329	0.91	0.144	0.93	0.149	138.02	0.207	2.82	0.89
CCOX 118	2.56	9.79	1.81	0.414	1.5	0.231	1.42	0.292	0.78	0.138	0.83	0.136	372.89	0.3	2.61	0.95
CCOX 119	2.59	10.28	1.97	0.427	1.6	0.269	1.57	0.332	0.88	0.136	0.93	0.153	139.57	0.202	2.79	0.91
CCOX 120	2.84	11.02	2.07	0.462	1.72	0.269	1.62	0.336	0.9	0.133	0.99	0.142	191.29	0.188	2.79	0.97
CCOX 45	2.83	11.22	2.17	0.475	1.82	0.291	1.76	0.346	0.93	0.143	1.02	0.143	213.02	0.219	2.89	0.9
CCOX 15	2.15	8.35	1.62	0.344	1.25	0.206	1.21	0.25	0.67	0.101	0.71	0.114	253.32	0.2	2.06	0.674
CCOX 58	2.46	10	1.85	0.436	1.63	0.243	1.46	0.312	0.85	0.122	0.86	0.133	120.08	0.167	2.46	0.8

LA-ICP-MS

Van Linge

Sample	Li7	Be9	B11	Al27	Ca43	Ca44	Sc45	Ti47	V51	Cr53	Mn55	Fe57	Co59	Ni60	Cu63
CCOX 09	7.57	0.56	173.19	14906.29	139466	140653.1	2.002	1091.3	12.98	13.03	4478.9	6037.07	21.22	22.71	48.1
CCOX 10	6.38	0.538	175.96	13444.92	143499	145513.1	1.852	1016.79	12	12.1	5075.73	5789	23.58	24.54	52.24
CCOX 11	6.84	0.528	166.06	14874.31	138599.5	140367.3	2.09	1123.99	12.92	13.38	4612.26	6246.58	23.54	23.8	51.1
CCOX 37	6.78	0.5	169.75	14935.43	139781	141153.4	2.139	1156.61	14	14.26	5000.06	6675.77	17.32	22.79	51.08
CCOX 42	7.07	0.535	163.29	14911.41	137865.5	139581.1	2.08	1112.17	12.95	12.88	4612.58	6294.51	21.69	22.95	53.23
CCOX 48	8.28	0.618	204.35	15073.16	142102.6	142868.7	2.141	1051.48	12.11	12.61	4497.51	5554.56	16.99	21.69	56.51
CCOX 101	7.87	0.578	205.59	15832.55	139472	140224.3	2.28	1165.31	13.82	13.99	4914.63	6300.79	11.54	22.14	54.41
CCOX 104	8.42	0.526	206.04	14175.8	141512.3	143226.1	2.148	1166.82	12.74	12.53	5772.69	6449.51	17	21.8	49.33
CCOX 105	13.76	0.493	197.35	15103.49	141161.1	141868.1	2.082	1047.81	12.15	12.44	5071.32	5673.88	21	23.75	59.24
CCOX 108	9.49	0.539	227.17	14564.07	142562.7	143583.4	2.17	1149.2	12.96	12.97	6050.32	6902.88	21.95	27.01	54.11
CCOX 109	7.34	0.573	215.36	15466.2	148574.2	149301	2.18	1136.36	13.12	13.89	5381.92	5956.07	7.13	22.47	52.93
CCOX 19	16.26	0.93	214.47	20729.17	124844.5	125715.9	3.53	1068.1	33.04	21.2	890.99	11276.16	6.93	24.7	22.88
CCOX 36	8.94	0.475	177.87	13938.22	141073.3	142011.1	2.043	1178.25	13.25	12.77	6225.04	6808.4	24.58	27.55	52.49
CCOX 40	8.66	0.49	189.56	13386.04	143439.4	144298.1	1.949	1152.31	13.62	13.72	6366.01	7544.86	21.39	27.2	56.74
CCOX 121	15.76	0.98	212.13	14200.5	154820	155447.5	2.747	1499.16	21.03	30.18	4701.18	12159.27	3798.01	1371.8	357.58

Sample	Zn66	Ga69	Ge72	As75	Rb85	Sr88	Y89	Zr90	Ag107	Sn118	Sb121	Cs133	Ba137	La139	Ce140
CCOX 09	120.72	17.45	0.742	79.86	83.93	596.31	6.45	179.66	0.168	449.04	0.87	0.539	2037.42	10.8	22
CCOX 10	154.65	18.14	0.914	97.14	101.75	695.07	6.65	183.42	0.255	18.62	0.81	0.612	2360.64	11.12	22.01
CCOX 11	134.83	17.18	0.824	93.37	92.07	654.57	7.73	211.04	0.183	500.09	1.01	0.572	2232.14	12.35	23.92
CCOX 37	130.95	17.59	0.833	55.1	79.54	674.29	7.37	209.31	0.152	67.63	1.37	0.531	2286.3	12.24	24.87
CCOX 42	133.48	17.15	0.813	81.42	83.72	629.9	6.98	193.46	0.161	518.53	1	0.515	2132.12	11.56	22.47
CCOX 48	126.29	18.34	0.681	46.94	83.79	544.22	6.2	167.66	0.265	19.29	0.756	0.473	1644.63	9.27	17.14
CCOX 101	112.63	18.14	0.764	15.95	73.76	567.35	6.6	184.74	0.145	54.76	1.094	0.488	1774.9	10.3	19.65
CCOX 104	139.35	19.06	0.676	22.37	71.36	630.13	6.35	169.71	0.19	10.58	0.881	0.457	2052.47	9.31	16.31
CCOX 105	110.29	18.79	0.74	65.52	75.32	577.94	6.61	170.45	0.155	67.76	0.716	0.473	1857.01	9.9	17.51
CCOX 108	160.07	20.89	0.764	48.59	72.77	643.12	6.46	165.01	0.178	13.67	1.137	0.48	2159.9	9.57	16.72
CCOX 109	120.82	20.12	0.682	9.99	72.17	601.31	6.59	181.55	0.304	59.57	0.704	0.453	1944.12	10.08	18.85
CCOX 19	243.42	9.55	1.48	26.96	33.85	1867.27	11.83	90.29	0.108	11.18	1.32	0.7	585.34	16.35	34.49
CCOX 36	168.58	20.3	0.75	62.7	85.18	769.28	7.46	191.23	0.199	15.2	1.27	0.61	2898.32	11.87	21.74
CCOX 40	168.19	20.26	0.866	47.74	82.98	767.79	6.79	179.79	0.238	16.28	1.4	0.568	2830.63	10.93	21.62
CCOX 121	514.25	11.55	1	6455.43	112.19	788.2	13.27	232.98	8.86	96.58	5.37	1.75	1296.16	20.04	35.92

Sample	Pr141	Nd146	Sm147	Eu153	Gd157	Tb159	Dy163	Ho165	Er166	Tm169	Yb172	Lu175	Pb208	Bi209	Th232	U238
CCOX 09	2.29	8.71	1.66	0.345	1.31	0.21	1.27	0.275	0.78	0.123	0.85	0.141	208.07	11.82	2.58	0.81
CCOX 10	2.34	8.93	1.63	0.362	1.28	0.214	1.3	0.266	0.78	0.12	0.84	0.133	160.85	10.45	2.54	0.83
CCOX 11	2.54	9.94	1.93	0.395	1.48	0.251	1.53	0.328	0.92	0.144	1.07	0.171	240.76	13.64	3.1	0.93
CCOX 37	2.62	9.94	1.89	0.397	1.47	0.239	1.49	0.324	0.88	0.136	1.01	0.163	209	4.78	2.89	0.93
CCOX 42	2.37	9.07	1.83	0.363	1.37	0.237	1.36	0.295	0.83	0.131	0.97	0.146	241.98	10.86	2.71	0.83
CCOX 48	1.88	7.18	1.36	0.286	1.098	0.181	1.108	0.23	0.67	0.1042	0.809	0.1153	113.98	6.74	2.37	0.72
CCOX 101	2.1	8.1	1.5	0.327	1.17	0.198	1.26	0.256	0.7	0.1099	0.879	0.1178	174.39	1.28	2.59	0.818
CCOX 104	1.88	7.3	1.44	0.3	1.09	0.189	1.138	0.231	0.727	0.1027	0.781	0.121	432.17	3.62	2.29	0.726
CCOX 105	1.98	7.67	1.44	0.301	1.132	0.187	1.2	0.238	0.695	0.1079	0.801	0.119	107.13	9.17	2.49	0.712
CCOX 108	1.9	7.37	1.38	0.309	1.139	0.184	1.138	0.246	0.702	0.1105	0.828	0.124	639.9	15.01	2.46	0.754
CCOX 109	2.04	7.73	1.4	0.308	1.135	0.191	1.165	0.239	0.686	0.1125	0.807	0.1154	143.45	0.969	2.47	0.733
CCOX 19	3.81	15.47	3.14	0.79	2.6	0.418	2.35	0.482	1.25	0.186	1.23	0.178	81.21	0.109	3.92	2.05
CCOX 36	2.48	9.46	1.9	0.378	1.47	0.256	1.46	0.307	0.87	0.129	0.98	0.162	679.67	18.24	2.82	0.87
CCOX 40	2.37	8.9	1.71	0.341	1.28	0.217	1.33	0.283	0.81	0.121	0.86	0.135	676.11	13.43	2.57	0.89
CCOX 121	4.19	16.32	3.49	0.72	2.94	0.463	2.67	0.556	1.45	0.217	1.54	0.233	381.9	1730.81	3.99	124.85

RI

Archaeological

Fragment	Comment	Operator	Calibration	Heating	Cooling	Mean RI	Date	Time
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Control Sample CCOX109: window glass, Plain non toughened

Control Sample CCOX118: window glass, Plain non toughened

Control Sample PD29: Roman, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	72.73(19)	72.225	1.51755	1.51755	1/9/2001	00:59
1/1.3	UWE Bristol	Oil B 589nm	72.48(52)	72.015	1.51763	1.51763	1/9/2001	00:59
1/1.4	UWE Bristol	Oil B 589nm	72.59(48)	72.11	1.51759	1.51759	1/9/2001	00:59
2/1.1	UWE Bristol	Oil B 589nm	72.09(45)	71.22	1.51792	1.51792	1/9/2001	01:11
2/1.2	UWE Bristol	Oil B 589nm	72.58(86)	71.775	1.51772	1.51772	1/9/2001	01:11
{*2/1.3	UWE Bristol	Oil B 589nm	70.23(40)	69.435	1.51857	1.51857	1/9/2001	01:11 *}
2/1.4	UWE Bristol	Oil B 589nm	72.51(18)	71.675	1.51775	1.51775	1/9/2001	01:11
3/1.1	UWE Bristol	Oil B 589nm	72.39(37)	71.545	1.5178	1.51780	1/9/2001	01:19
3/1.2	UWE Bristol	Oil B 589nm	72.30(49)	71.465	1.51783	1.51783	1/9/2001	01:19
3/1.3	UWE Bristol	Oil B 589nm	72.25(99)	71.395	1.51786	1.51786	1/9/2001	01:19
3/1.4	UWE Bristol	Oil B 589nm	72.37(99)	71.535	1.5178	1.51780	1/9/2001	01:19

Mean of 10 Samples: 71.70 Range: 71.22 - 72.22 SD: 0.313
1.51775 Range: 1.51755 - 1.51792 SD: 0.0001154

Control Sample PD26: Roman, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	86.37(50)	85.37	1.51273	1.51273	1/9/2001	01:37
1/1.2	UWE Bristol	Oil B 589nm	86.66(88)	85.64	1.51263	1.51263	1/9/2001	01:37
1/1.3	UWE Bristol	Oil B 589nm	86.37(99)	85.405	1.51272	1.51272	1/9/2001	01:37
1/1.4	UWE Bristol	Oil B 589nm	86.29(64)	85.3	1.51276	1.51276	1/9/2001	01:37

2/1.1	UWE Bristol	Oil B 589nm	86.38(99)	85.44	1.51271	1.51271	1/9/2001	01:49
2/1.2	UWE Bristol	Oil B 589nm	86.42(14)	85.485	1.51269	1.51269	1/9/2001	01:49
2/1.3	UWE Bristol	Oil B 589nm	86.35(99)	85.4	1.51272	1.51272	1/9/2001	01:49
2/1.4	UWE Bristol	Oil B 589nm	86.33(5)	85.44	1.51271	1.51271	1/9/2001	01:49
3/1.1	UWE Bristol	Oil B 589nm	86.41(99)	85.485	1.51269	1.51269	1/9/2001	01:57
3/1.2	UWE Bristol	Oil B 589nm	86.43(66)	85.505	1.51269	1.51269	1/9/2001	01:57
3/1.3	UWE Bristol	Oil B 589nm	86.54(24)	85.65	1.51263	1.51263	1/9/2001	01:57
3/1.4	UWE Bristol	Oil B 589nm	86.37(80)	85.43	1.51271	1.51271	1/9/2001	01:57
Mean of 12 Samples:				85.46	Range: 85.30 - 85.65	SD: 0.097		
				1.51270	Range: 1.51263 - 1.51276	SD: 0.0000362		

Control Sample COP9: Egyptian, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	63.30(99)	62.51	1.52111	1.52111	1/9/2001	02:29
1/1.2	UWE Bristol	Oil B 589nm	62.66(99)	61.85	1.52135	1.52135	1/9/2001	02:29
1/1.3	UWE Bristol	Oil B 589nm	62.41(30)	61.575	1.52145	1.52145	1/9/2001	02:29
1/1.4	UWE Bristol	Oil B 589nm	61.90(81)	61.04	1.52165	1.52165	1/9/2001	02:29
{*2/1.1	UWE Bristol	Oil B 589nm	60.44(8)	59.69	1.52214	1.52214	1/9/2001	02:37 *}
2/1.2	UWE Bristol	Oil B 589nm	61.72(63)	60.855	1.52172	1.52172	1/9/2001	02:37
2/1.3	UWE Bristol	Oil B 589nm	61.31(33)	60.46	1.52186	1.52186	1/9/2001	02:37
2/1.4	UWE Bristol	Oil B 589nm	61.44(34)	60.58	1.52182	1.52182	1/9/2001	02:37
3/1.3	UWE Bristol	Oil B 589nm	61.21(99)	60.445	1.52187	1.52187	1/9/2001	02:46
3/1.4	UWE Bristol	Oil B 589nm	61.25(85)	60.425	1.52187	1.52187	1/9/2001	02:46
Mean of 9 Samples:				61.08	Range: 60.42 - 62.51	SD: 0.699		
				1.52163	Range: 1.52111 - 1.52187	SD: 0.0002568		

Control Sample UPP3: Egyptian, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	34.91(13)	34.25	1.53146	1.53146	1/9/2001	03:01
1/1.2	UWE Bristol	Oil B 589nm	35.24(8)	34.55	1.53135	1.53135	1/9/2001	03:01
1/1.3	UWE Bristol	Oil B 589nm	35.43(4)	34.77	1.53127	1.53127	1/9/2001	03:01
1/1.4	UWE Bristol	Oil B 589nm	35.17(3)	34.515	1.53137	1.53137	1/9/2001	03:01

2/1.1	UWE Bristol	Oil B 589nm	35.35(15)	34.705	1.5313	1.53130	1/9/2001	03:13
2/1.2	UWE Bristol	Oil B 589nm	35.24(43)	34.565	1.53135	1.53135	1/9/2001	03:13
2/1.3	UWE Bristol	Oil B 589nm	35.11(26)	34.46	1.53139	1.53139	1/9/2001	03:13
2/1.4	UWE Bristol	Oil B 589nm	35.50(4)	34.8	1.53126	1.53126	1/9/2001	03:13
3/1.1	UWE Bristol	Oil B 589nm	35.14(99)	34.46	1.53139	1.53139	1/9/2001	03:24
3/1.2	UWE Bristol	Oil B 589nm	35.08(99)	34.405	1.53141	1.53141	1/9/2001	03:24
3/1.3	UWE Bristol	Oil B 589nm	35.00(99)	34.325	1.53144	1.53144	1/9/2001	03:24
3/1.4	UWE Bristol	Oil B 589nm	35.03(99)	34.355	1.53143	1.53143	1/9/2001	03:24
Mean of 12 Samples: 34.51 Range: 34.25 - 34.80 SD: 0.167								
1.53137 Range: 1.53126 - 1.53146 SD: 0.0000624								

Control Sample CCOX102: Medieval, Archaeological

1/1.1	UWE Bristol	Oil A 589nm	40.65(8)	39.935	1.55046	1.55046	1/9/2001	05:29
1/1.2	UWE Bristol	Oil A 589nm	40.82(14)	39.975	1.55045	1.55045	1/9/2001	05:29
1/1.3	UWE Bristol	Oil A 589nm	40.55(9)	39.795	1.55052	1.55052	1/9/2001	05:29
1/1.4	UWE Bristol	Oil A 589nm	40.89(9)	40.07	1.55041	1.55041	1/9/2001	05:29
2/1.1	UWE Bristol	Oil A 589nm	40.35(15)	39.605	1.5506	1.55060	1/9/2001	05:38
2/1.2	UWE Bristol	Oil A 589nm	40.70(11)	39.895	1.55048	1.55048	1/9/2001	05:38
2/1.3	UWE Bristol	Oil A 589nm	40.67(3)	39.795	1.55052	1.55052	1/9/2001	05:38
2/1.4	UWE Bristol	Oil A 589nm	40.57(9)	39.81	1.55051	1.55051	1/9/2001	05:38
3/1.1	UWE Bristol	Oil A 589nm	40.70(16)	39.955	1.55045	1.55045	1/9/2001	05:47
3/1.2	UWE Bristol	Oil A 589nm	40.71(42)	39.875	1.55049	1.55049	1/9/2001	05:47
3/1.3	UWE Bristol	Oil A 589nm	40.71(79)	39.885	1.55048	1.55048	1/9/2001	05:47
3/1.4	UWE Bristol	Oil A 589nm	40.48(19)	39.67	1.55057	1.55057	1/9/2001	05:47
Mean of 12 Samples: 39.86 Range: 39.60 - 40.07 SD: 0.124								
1.55049 Range: 1.55041 - 1.55060 SD: 0.0000509								

Control Sample CCOX103: Victorian, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	35.76(12)	34.995	1.53119	1.53119	1/9/2001	04:26
1/1.2	UWE Bristol	Oil B 589nm	35.89(1)	35.19	1.53112	1.53112	1/9/2001	04:26

1/1.3	UWE Bristol	Oil B 589nm	35.73(21)	35.065	1.53117	1.53117	1/9/2001	04:26
1/1.4	UWE Bristol	Oil B 589nm	34.92(24)	34.265	1.53146	1.53146	1/9/2001	04:26
2/1.1	UWE Bristol	Oil B 589nm	35.94(9)	35.33	1.53107	1.53107	1/9/2001	04:42
2/1.2	UWE Bristol	Oil B 589nm	37.39(9)	36.685	1.53057	1.53057	1/9/2001	04:42
2/1.3	UWE Bristol	Oil B 589nm	36.51(16)	35.785	1.5309	1.53090	1/9/2001	04:42
2/1.4	UWE Bristol	Oil B 589nm	37.11(39)	36.45	1.53066	1.53066	1/9/2001	04:42
3/1.1	UWE Bristol	Oil B 589nm	35.79(79)	35.11	1.53115	1.53115	1/9/2001	04:53
3/1.2	UWE Bristol	Oil B 589nm	36.08(99)	35.41	1.53104	1.53104	1/9/2001	04:53
3/1.3	UWE Bristol	Oil B 589nm	36.31(99)	35.645	1.53095	1.53095	1/9/2001	04:53
3/1.4	UWE Bristol	Oil B 589nm	36.59(99)	35.91	1.53085	1.53085	1/9/2001	04:53

Mean of 12 Samples: 35.49 Range: 34.26 - 36.69 SD: 0.634
1.53101 Range: 1.53057 - 1.53146 SD: 0.0002335

Control Sample CCOX01: Victorian, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	40.50(45)	39.76	1.52944	1.52944	1/9/2001	05:04
1/1.2	UWE Bristol	Oil B 589nm	40.49(72)	39.745	1.52945	1.52945	1/9/2001	05:04
1/1.3	UWE Bristol	Oil B 589nm	40.48(99)	39.76	1.52944	1.52944	1/9/2001	05:04
1/1.4	UWE Bristol	Oil B 589nm	40.50(99)	39.765	1.52944	1.52944	1/9/2001	05:04
2/1.1	UWE Bristol	Oil B 589nm	40.45(99)	39.67	1.52948	1.52948	1/9/2001	05:11
2/1.2	UWE Bristol	Oil B 589nm	40.55(99)	39.765	1.52944	1.52944	1/9/2001	05:11
2/1.3	UWE Bristol	Oil B 589nm	40.52(99)	39.74	1.52945	1.52945	1/9/2001	05:11
2/1.4	UWE Bristol	Oil B 589nm	40.54(91)	39.735	1.52945	1.52945	1/9/2001	05:11
3/1.1	UWE Bristol	Oil B 589nm	40.52(61)	39.735	1.52945	1.52945	1/9/2001	05:18
3/1.2	UWE Bristol	Oil B 589nm	40.44(69)	39.65	1.52948	1.52948	1/9/2001	05:18
3/1.3	UWE Bristol	Oil B 589nm	40.86(99)	40.09	1.52932	1.52932	1/9/2001	05:18
3/1.4	UWE Bristol	Oil B 589nm	40.72(47)	39.915	1.52939	1.52939	1/9/2001	05:18

Mean of 12 Samples: 39.78 Range: 39.65 - 40.09 SD: 0.112
1.52944 Range: 1.52932 - 1.52948 SD: 0.0000411

Control Sample CCOX123: Medieval, Archaeological

1/1.1	UWE Bristol	Oil B 589nm	68.68(20)	67.76	1.51919	1.51919	1/9/2001	06:06
1/1.2	UWE Bristol	Oil B 589nm	68.63(30)	67.68	1.51921	1.51921	1/9/2001	06:06
1/1.3	UWE Bristol	Oil B 589nm	68.71(43)	67.83	1.51916	1.51916	1/9/2001	06:06
1/1.4	UWE Bristol	Oil B 589nm	69.12(28)	68.475	1.51892	1.51892	1/9/2001	06:06
2/1.1	UWE Bristol	Oil B 589nm	68.70(93)	67.8	1.51917	1.51917	1/9/2001	06:12
2/1.2	UWE Bristol	Oil B 589nm	69.55(17)	68.65	1.51886	1.51886	1/9/2001	06:12
2/1.3	UWE Bristol	Oil B 589nm	69.63(81)	68.775	1.51882	1.51882	1/9/2001	06:12
2/1.4	UWE Bristol	Oil B 589nm	69.41(16)	68.525	1.51891	1.51891	1/9/2001	06:12
3/1.1	UWE Bristol	Oil B 589nm	69.41(21)	68.495	1.51892	1.51892	1/9/2001	06:19
3/1.2	UWE Bristol	Oil B 589nm	68.53(44)	67.625	1.51924	1.51924	1/9/2001	06:19
3/1.3	UWE Bristol	Oil B 589nm	69.28(97)	68.43	1.51894	1.51894	1/9/2001	06:19
3/1.4	UWE Bristol	Oil B 589nm	68.46(62)	67.595	1.51925	1.51925	1/9/2001	06:19

Mean of 12 Samples: 68.14 Range: 67.60 - 68.78 SD: 0.434

1.51905

Range:

1.51882

-

1.51925

SD:

0.0001587

SEM-WDS

Cars

Comment	SiO2	Al2O3	CaO	MgO	Na2O	K2O	FeO	TiO2	CoO	CuO	MnO
AuAUD02	70.19	0.74	8.85	3.90	13.16	0.24	0.76	0.04	0.03	0.04	0.03
AuBMW02	70.06	0.28	9.07	4.04	13.31	0.08	0.62	0.01	0.01	0.06	0.02
AuCIT01	70.34	1.14	8.38	4.23	13.15	0.14	0.46	0.07	0.01	0.07	0.00
AuCIT02	69.60	0.73	9.44	4.21	13.50	0.17	0.60	0.05	0.03	0.17	0.05
AuDAE01	69.05	1.83	8.38	4.29	12.91	0.68	0.41	0.13	0.01	0.03	0.02
AuFIA01	68.59	1.11	9.94	3.94	13.56	0.53	0.47	0.02	0.01	0.05	0.04
AuFIA02	70.72	0.44	8.78	3.99	13.63	0.25	0.11	0.06	0.04	0.05	0.01
AuFOR01	69.53	0.67	9.02	4.11	13.79	0.32	0.41	0.02	0.04	0.02	0.03
AuFOR02	70.59	0.73	8.87	3.89	13.17	0.24	0.70	0.03	0.01	0.04	0.03
AuFOR03	70.67	1.09	8.51	3.85	12.60	0.64	0.06	0.02	0.06	0.02	0.02
AuFOR04	70.76	1.11	8.56	3.93	12.72	0.65	0.12	0.02	0.02	0.06	0.00
AuFOR05	71.05	1.10	8.50	3.92	12.81	0.65	0.10	0.05	0.03	0.06	0.02
AuNIS01	68.79	2.06	9.15	3.57	13.15	0.82	0.07	0.05	0.04	0.00	0.01
AuREN01	69.63	1.05	8.62	4.35	13.77	0.17	0.58	0.06	0.05	0.04	0.03
AuREN02	69.36	0.67	9.74	4.07	13.40	0.24	0.10	0.05	0.11	0.05	0.00
AuROV01	70.19	0.61	8.96	3.94	13.37	0.32	0.59	0.04	0.02	0.02	0.00
AuROV02	70.18	0.71	8.91	4.09	13.03	0.24	0.77	0.04	0.09	0.00	0.01

AuTOY01	69.17	1.59	8.92	3.90	13.24	0.75	0.34	0.06	0.00	0.02	0.05
AuVAU01	69.44	0.55	9.03	4.48	13.67	0.26	0.08	0.05	0.05	0.11	0.00
AuVAU02	70.51	0.31	8.96	3.90	13.76	0.06	0.55	0.03	0.01	0.05	0.02
AuVW01	69.39	0.67	8.84	4.83	13.49	0.15	0.45	0.03	0.00	0.02	0.02
AuVW02	69.66	0.69	8.99	3.89	13.90	0.19	0.77	0.04	0.00	0.05	0.00
AuVW03	69.20	0.66	8.64	5.01	13.48	0.15	0.45	0.08	0.01	0.01	0.01
AuVW04	69.68	0.63	9.58	3.97	13.50	0.20	0.11	0.03	0.01	0.02	0.02

Comment	NiO	ZnO	As2O5	SnO2	Sb2O5	BaO	PbO2	Cr2O3	P2O5	SO3	Cl	Total
AuAUD02	0.05	0.01	0.04	0.02	0.00	0.01	0.00	0.01	0.01	0.10	0.03	98.24
AuBMW02	0.03	0.02	0.02	0.03	0.00	0.00	0.03	0.04	0.04	0.20	0.01	97.96
AuCIT01	0.06	0.06	0.06	0.02	0.00	0.01	0.01	0.00	0.03	0.09	0.01	98.34
AuCIT02	0.05	0.16	0.03	0.03	0.00	0.02	0.01	0.01	0.02	0.22	0.04	99.12
AuDAE01	0.02	0.01	0.04	0.04	0.00	0.01	0.02	0.03	0.01	0.19	0.01	98.12
AuFIA01	0.04	0.06	0.04	0.01	0.00	0.04	0.00	0.00	0.03	0.21	0.04	98.71
AuFIA02	0.06	0.25	0.04	0.00	0.00	0.05	0.05	0.00	0.03	0.24	0.01	98.81
AuFOR01	0.02	0.00	0.04	0.02	0.00	0.02	0.02	0.00	0.03	0.19	0.03	98.30
AuFOR02	0.07	0.03	0.02	0.00	0.00	0.01	0.03	0.01	0.02	0.10	0.03	98.62
AuFOR03	0.05	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.02	0.11	0.01	97.78
AuFOR04	0.07	0.09	0.04	0.01	0.00	0.00	0.02	0.01	0.02	0.15	0.03	98.38

AuFOR05	0.04	0.02	0.03	0.04	0.00	0.00	0.02	0.03	0.04	0.14	0.01	98.64
AuNIS01	0.03	0.16	0.05	0.05	0.00	0.02	0.02	0.03	0.01	0.13	0.02	98.22
AuREN01	0.01	0.09	0.02	0.01	0.00	0.01	0.06	0.00	0.03	0.09	0.02	98.65
AuREN02	0.01	0.04	0.05	0.02	0.00	0.02	0.03	0.06	0.02	0.25	0.04	98.30
AuROV01	0.01	0.02	0.01	0.00	0.00	0.04	0.00	0.03	0.02	0.18	0.02	98.37
AuROV02	0.09	0.07	0.03	0.00	0.00	0.02	0.02	0.04	0.02	0.15	0.03	98.53
AuTOY01	0.04	0.01	0.02	0.01	0.00	0.06	0.00	0.01	0.02	0.20	0.02	98.43
AuVAU01	0.02	0.09	0.03	0.01	0.02	0.02	0.01	0.01	0.03	0.26	0.03	98.25
AuVAU02	0.01	0.03	0.06	0.02	0.00	0.04	0.02	0.05	0.02	0.16	0.02	98.59
AuVW01	0.01	0.07	0.07	0.01	0.00	0.02	0.00	0.02	0.01	0.20	0.02	98.33
AuVW02	0.03	0.12	0.03	0.02	0.00	0.04	0.02	0.02	0.00	0.21	0.01	98.70
AuVW03	0.02	0.06	0.06	0.04	0.00	0.00	0.04	0.01	0.01	0.17	0.03	98.12
AuVW04	0.03	0.01	0.03	0.06	0.00	0.01	0.06	0.02	0.02	0.20	0.02	98.20

LA-ICP-MS

Cars

	Li7	Be9	B11	Al27	Ca43	Ca44	Sc45	Ti47	V51	Cr53	Mn55	Fe57	Co59	Ni60	Cu63
AuAUD02	3.3	0.059	8.35	3683.09	63147.51	63251.02	0.55	192.09	2.88	5.33	79.53	7084.63	0.279	1.726	4.89
AuBMW02	0.779	0.083	12.73	1374.4	64777.05	64823.36	0.786	108.93	1.948	4.78	23.55	5965.8	0.442	1.036	5.15
AuCIT01	2.532	0.361	43.6	5265.09	59536.49	59891.94	0.861	428.56	3.84	5.13	23.12	3775.01	2.042	8.27	3.36
AuCIT02	3.55	0.223	12.46	3399.04	67482.45	67467.77	1.046	143.35	4.18	4.87	81.2	5072.28	9.89	2.39	4.04
AuDAE01	4.49	0.386	10.93	8751.97	59148.3	59891.93	2.03	767.28	4.68	6.92	129.71	4066.92	2.83	1.113	5.76
AuFIA01	3.92	0.159	16.35	5380.78	71074.34	71041.27	0.712	86.23	2.245	2.81	21.61	3450.49	6.1	0.791	3.19
AuFIA02	2.62	0.064	18.33	2131.97	62177.63	62750.74	0.875	328.4	2.027	3.21	23.17	789.45	0.371	0.757	3.52
AuFOR01	4.35	1.22	17.33	3132.85	64191.83	64466.03	0.627	75.28	2.548	2.29	33.34	3421.4	0.735	1.383	3.59
AuFOR02	3.26	0.053	10.59	3421.65	63174.86	63393.97	0.582	196.08	2.839	6.33	70.83	5901.27	0.324	2.21	4.31
AuFOR03	8.28	0.129	23.81	5142.88	60651.84	60821.05	0.764	187.45	2.837	3.22	68.09	730.93	0.559	1.315	4.18
AuFOR04	7.94	0.102	19.97	5286.9	60939.94	61178.41	0.742	194.17	2.741	2.87	64.26	721.04	0.468	1.183	3.83
AuFOR05	8.05	0.111	19.78	5032.44	60455.83	60749.58	0.736	186.25	3.51	3.2	64	719.64	0.604	1.697	4.6
AuNIS01	5.52	0.444	10.6	10167.48	65081.15	65395.12	1.499	242.81	4	5.52	224.38	622.6	0.951	1.545	6.25
AuREN01	5.65	0.52	17.36	4987.27	61289.77	61607.22	1.54	257.44	4.82	4.27	128.95	4155.86	1.058	2.02	3.32
AuREN02	6.4	0.347	24.4	3191.82	69164.07	69611.88	2.074	177.85	7.37	2.83	109.07	476.21	0.123	0.929	3.15
AuROV01	2.24	0.098	8.58	2938.44	63036.23	64037.19	0.659	253.22	2.93	6.75	42.28	5094.86	1.093	2.64	5.23
AuROV02	3.03	0.075	14.39	3698.1	63104.57	63679.84	0.637	213.7	4.61	7.43	75.61	7837.02	0.37	2.35	5.68
AuTOY01	6.43	0.157	13.42	7793.37	63394.56	63751.33	0.651	160.16	3.16	1.91	46.51	2418.85	13.83	1.323	3.33

AuVAU01	2.72	0.052	12.83	2793.33	64229.27	64537.48	0.798	209.43	6.47	8.83	22.07	720.59	0.708	2.22	4.44
AuVAU02	2.38	0.298	19.72	1543.43	64152.05	64037.2	0.794	109.36	2.073	3.47	61.18	5075.73	0.1219	0.315	4.03
AuVW01	11.14	0.289	29.12	3419.66	63072.37	63179.55	0.859	311.4	6.05	12.4	18.69	4265.54	5.89	2.34	4.34
AuVW02	4.15	0.14	8.88	3448.47	63902.22	64251.61	1.046	301.56	3.78	7.25	98.28	7098.62	1.805	2.23	5.75
AuVW03	10.16	0.244	27.58	3128.72	61318.98	61750.15	0.846	306.54	5.85	10.11	18.81	4307.68	4.03	2.35	4.64
AuVW04	3.74	0.078	8.64	3099.08	67819	68468.34	0.618	307.05	3.08	4.43	73.39	832.09	0.42	1.047	4.71

	Zn66	Ga69	Ge72	As75	Rb85	Sr88	Y89	Zr90	Ag107	Sn118	Sb121	Cs133	Ba137	La139	Ce140
AuAUD02	11.13	0.992	0.552	0.617	3.74	98.11	2.92	45.37	0.0402	13.72	0.184	0.0528	91.97	2.49	3.74
AuBMW02	2.84	0.323	0.521	0.58	2.19	117.94	1.71	22.4	0.0154	15.15	0.155	0.0953	14.57	3.56	8.34
AuCIT01	2.32	1.106	0.752	0.515	4.9	29.38	2.246	82.13	0.0131	16.23	0.316	0.1746	18.19	1.251	2.157
AuCIT02	10.6	0.909	0.528	0.52	4.53	36.53	3.62	89.72	0.124	11.19	0.108	0.0924	31.11	3.44	5.95
AuDAE01	7.51	1.544	0.629	0.68	15.03	96.3	6.62	147.46	0.195	32.73	0.152	0.149	88.2	4.26	14.79
AuFIA01	2.95	1.409	0.67	1.1	18.1	31.32	1.634	27.46	<0.0125	11.66	0.14	0.393	79.23	2.05	2.89
AuFIA02	2.84	1.018	0.54	0.36	5.48	28.43	2.176	118.25	<0.0141	8.77	0.066	0.091	78.77	3.83	7.28
AuFOR01	3.32	0.901	0.712	0.534	27.58	138.08	2.27	68.83	0.0213	8.65	0.057	1.68	16.71	1.74	2.8
AuFOR02	7.89	1.589	0.599	0.515	3.78	111.71	3.01	51.5	0.0333	8.98	0.109	0.054	97.98	3.16	4.1
AuFOR03	10.13	2.41	0.843	0.579	20.08	44.53	2.32	50.29	0.0333	9.3	0.285	0.588	120.72	3.54	6.49
AuFOR04	5.22	2.4	0.727	0.675	20.57	40.75	2.45	46.98	0.0355	8.09	0.254	0.589	125.76	3.6	6.42
AuFOR05	8.31	2.44	0.809	0.74	20.9	39.5	2.35	43.1	0.0403	7.34	0.284	0.609	130.29	3.6	6.73
AuNIS01	9.03	2.15	0.672	0.407	18.47	63.48	4.89	36.1	1.74	12.31	0.145	0.244	191.28	3.96	8.4
AuREN01	9.95	0.825	0.558	0.334	4.14	43.47	5.86	59.96	0.0232	14.3	0.104	0.1129	47.03	5.37	9.99
AuREN02	10.88	0.678	0.542	0.4	5.12	50.79	7.61	33.1	<0.0128	5.86	0.107	0.1272	61.38	8.07	15.39

AuROV01	3.26	1.045	0.558	0.464	7.42	47.83	2.67	152.64	0.0228	17.55	0.063	0.1199	111.99	4.29	8.96
AuROV02	13.14	0.995	0.587	0.89	4.35	95.69	3.56	56.5	0.027	13.57	0.224	0.0767	83.64	3.28	4.87
AuTOY01	8.89	2.47	0.62	1.17	22.37	46.25	2.4	19.14	0.0125	20.85	0.154	0.611	100.28	2.1	8.12
AuVAU01	1.33	0.697	0.478	0.271	7.64	21.09	2.81	138.92	0.0107	12.85	0.116	0.145	32.06	3.88	7.61
AuVAU02	4.77	0.339	0.436	0.198	1.006	72.4	2.43	37.68	0.0142	11.83	0.126	0.0378	22.39	2.87	5.39
AuVW01	3.49	0.796	0.733	0.64	5.09	21.18	4	45.82	0.0121	13.92	0.206	0.264	21.31	4.09	8.62
AuVW02	26.41	0.918	0.55	0.43	3.57	91.08	4.76	72.01	0.02	18.46	0.145	0.0982	77.89	4.03	7.22
AuVW03	4.82	0.797	0.775	0.84	5.19	22.13	4.16	45.8	0.0185	15.67	0.212	0.257	21.73	4.2	8.8
AuVW04	33.47	0.941	0.571	0.7	3.51	92.43	3.59	62.63	0.0105	12.63	0.18	0.083	80.44	3.01	4.43

	Pr141	Nd146	Sm147	Eu153	Gd157	Tb159	Dy163	Ho165	Er166	Tm169	Yb172	Lu175	Pb208	Bi209	Th232	U238
AuAUD02	0.503	1.87	0.387	0.075	0.359	0.0633	0.376	0.0868	0.238	0.036	0.228	0.0351	3.65	0.0477	0.393	0.378
AuBMW02	0.762	2.8	0.473	0.0699	0.339	0.0566	0.325	0.07	0.187	0.0297	0.226	0.0349	2.88	2.2	2.57	0.455
AuCIT01	0.252	0.959	0.188	0.0325	0.218	0.0415	0.324	0.0741	0.251	0.0407	0.309	0.0552	2.413	0.0198	1.329	0.682
AuCIT02	0.724	2.85	0.588	0.0987	0.492	0.0855	0.549	0.1142	0.327	0.0494	0.344	0.056	5.78	0.0226	1.026	0.532
AuDAE01	1.036	4	0.836	0.22	0.944	0.143	1.026	0.227	0.717	0.11	0.782	0.128	1.736	0.0183	1.248	1.58
AuFIA01	0.381	1.483	0.263	0.0761	0.248	0.0396	0.246	0.0535	0.159	0.025	0.172	0.0287	2.323	0.0084	0.652	0.358
AuFIA02	0.771	2.92	0.535	0.1055	0.389	0.0611	0.376	0.0782	0.227	0.0368	0.288	0.0423	1.758	0.0055	0.94	0.356
AuFOR01	0.344	1.44	0.335	0.0633	0.393	0.0578	0.377	0.0836	0.254	0.0395	0.308	0.051	2.89	0.0758	0.703	0.369
AuFOR02	0.567	2.33	0.452	0.0991	0.424	0.0705	0.441	0.0962	0.241	0.035	0.249	0.038	2.74	0.0144	0.417	0.375
AuFOR03	0.736	2.79	0.547	0.116	0.433	0.0691	0.399	0.0922	0.237	0.0339	0.264	0.0405	3.39	0.0131	0.937	0.621
AuFOR04	0.745	2.83	0.528	0.125	0.423	0.0696	0.431	0.0896	0.248	0.0388	0.275	0.0384	3.6	0.0101	0.896	0.603
AuFOR05	0.745	2.86	0.554	0.133	0.43	0.0679	0.418	0.0895	0.247	0.0354	0.266	0.0379	3.6	0.0143	0.94	0.687

AuNIS01	0.847	3.06	0.653	0.203	0.662	0.0961	0.675	0.145	0.417	0.0649	0.426	0.0725	31.04	0.0212	1.115	0.625
AuREN01	1.065	4.43	0.931	0.224	0.872	0.1337	0.869	0.1892	0.537	0.0738	0.516	0.084	2.78	0.033	1.29	0.818
AuREN02	1.834	7.59	1.518	0.288	1.297	0.214	1.233	0.258	0.685	0.1028	0.666	0.0939	4.82	0.0076	1.939	0.688
AuROV01	0.975	3.54	0.645	0.136	0.573	0.0746	0.487	0.0962	0.29	0.0487	0.323	0.0519	2.18	0.0117	1.162	0.567
AuROV02	0.681	2.55	0.514	0.0919	0.466	0.0804	0.517	0.1037	0.296	0.0357	0.281	0.0485	4.55	0.0117	0.616	0.456
AuTOY01	0.347	1.39	0.281	0.0778	0.238	0.042	0.293	0.0647	0.19	0.0291	0.226	0.036	3.39	0.0247	0.619	0.24
AuVAU01	0.883	3.26	0.61	0.1218	0.499	0.0651	0.455	0.0878	0.289	0.0483	0.321	0.0552	2.022	0.0076	1.204	0.474
AuVAU02	0.651	2.59	0.515	0.1275	0.458	0.0714	0.374	0.0715	0.23	0.038	0.237	0.038	6.81	0.0156	0.556	0.37
AuVW01	0.982	3.74	0.78	0.1145	0.661	0.1015	0.609	0.1241	0.35	0.0642	0.36	0.0508	1.716	0.021	1.54	0.719
AuVW02	0.932	3.47	0.658	0.142	0.699	0.0965	0.692	0.135	0.421	0.0602	0.418	0.0606	3.35	0.0056	0.901	0.473
AuVW03	1.042	3.86	0.769	0.1183	0.701	0.101	0.618	0.1222	0.355	0.0516	0.354	0.0528	1.946	0.0209	1.52	0.799
AuVW04	0.618	2.26	0.468	0.0986	0.447	0.0683	0.433	0.0993	0.287	0.0416	0.266	0.0425	7.46	0.0095	0.448	0.537

Isotopes

Cars

Sample	$^{143}\text{Nd}/^{144}\text{Nd}$	$^{87}\text{Sr}/^{86}\text{Sr}$
VW1	0.512139	0.710756
VW2	0.511891	0.706246
VW3	0.512101	0.711331
VW4	0.512150	0.706158
ROV1	0.511925	0.712420
ROV2	0.512119	0.705913
FOR1	0.511869	0.711908
FOR2	0.512143	0.705751
FOR3	0.512091	0.714447
FOR4	0.512076	0.715194
FOR5	0.512097	0.715433
CIT1	0.512059	0.710424
CIT2	0.511982	0.710712
FIA1	0.512175	0.713897
FIA2	0.511870	0.713897
NIS1	0.512000	0.710151
TOY1	0.512296	0.708200
AUD2	0.512130	0.705694
BMW2	0.511241	0.709872

RI

Cars

Fragment	Comment	Operator	Calibration	Heating	Cooling	Mean RI	Date	Time
Control Sample AuAUD02: car, Float Toughened								
1/1.1	UWE Bristol	Oil B 589nm	65.92(99)	65.215	1.52012	1.52012	3/20/2001	02:35
1/1.2	UWE Bristol	Oil B 589nm	66.02(50)	65.34	1.52007	1.52007	3/20/2001	02:35
1/1.3	UWE Bristol	Oil B 589nm	65.92(17)	65.22	1.52012	1.52012	3/20/2001	02:35
1/1.4	UWE Bristol	Oil B 589nm	65.89(19)	65.145	1.52015	1.52015	3/20/2001	02:35
2/1.1	UWE Bristol	Oil B 589nm	66.17(16)	65.555	1.51999	1.51999	3/20/2001	02:44
2/1.2	UWE Bristol	Oil B 589nm	66.07(36)	65.395	1.52005	1.52005	3/20/2001	02:44
2/1.3	UWE Bristol	Oil B 589nm	66.09(68)	65.44	1.52004	1.52004	3/20/2001	02:44
2/1.4	UWE Bristol	Oil B 589nm	66.02(27)	65.305	1.52009	1.52009	3/20/2001	02:44
3/1.1	UWE Bristol	Oil B 589nm	66.53(48)	65.825	1.5199	1.51990	3/20/2001	02:51
3/1.2	UWE Bristol	Oil B 589nm	66.57(47)	65.875	1.51988	1.51988	3/20/2001	02:51
3/1.3	UWE Bristol	Oil B 589nm	66.48(57)	65.775	1.51991	1.51991	3/20/2001	02:51
3/1.4	UWE Bristol	Oil B 589nm	66.48(99)	65.785	1.51991	1.51991	3/20/2001	02:51
4/1.1	UWE Bristol	Oil B 589nm	66.34(20)	65.515	1.52001	1.52001	3/20/2001	03:00
4/1.2	UWE Bristol	Oil B 589nm	66.76(13)	65.92	1.51986	1.51986	3/20/2001	03:00
4/1.3	UWE Bristol	Oil B 589nm	65.61(8)	64.815	1.52027	1.52027	3/20/2001	03:00
4/1.4	UWE Bristol	Oil B 589nm	66.25(17)	65.49	1.52002	1.52002	3/20/2001	03:00
5/1.1	UWE Bristol	Oil B 589nm	66.20(48)	65.33	1.52008	1.52008	3/20/2001	03:07
5/1.2	UWE Bristol	Oil B 589nm	66.21(65)	65.345	1.52007	1.52007	3/20/2001	03:07
5/1.3	UWE Bristol	Oil B 589nm	66.23(43)	65.33	1.52008	1.52008	3/20/2001	03:07
5/1.4	UWE Bristol	Oil B 589nm	65.98(27)	65.085	1.52017	1.52017	3/20/2001	03:07
6/1.1	UWE Bristol	Oil B 589nm	67.05(10)	66.21	1.51975	1.51975	3/20/2001	03:16
6/1.2	UWE Bristol	Oil B 589nm	66.25(47)	65.43	1.52004	1.52004	3/20/2001	03:16
6/1.3	UWE Bristol	Oil B 589nm	65.40(26)	64.54	1.52036	1.52036	3/20/2001	03:16

6/1.4	UWE Bristol	Oil B 589nm	66.18(45)	65.37	1.52006	1.52006	3/20/2001	03:16			
7/1.1	UWE Bristol	Oil B 589nm	66.22(54)	65.3	1.52009	1.52009	3/20/2001	03:25			
7/1.2	UWE Bristol	Oil B 589nm	66.04(40)	65.055	1.52018	1.52018	3/20/2001	03:25			
7/1.3	UWE Bristol	Oil B 589nm	66.19(51)	65.265	1.5201	1.52010	3/20/2001	03:25			
7/1.4	UWE Bristol	Oil B 589nm	66.39(78)	65.5	1.52001	1.52001	3/20/2001	03:25			
8/1.1	UWE Bristol	Oil B 589nm	65.95(64)	65.02	1.52019	1.52019	3/20/2001	03:34			
8/1.2	UWE Bristol	Oil B 589nm	66.54(43)	65.635	1.51997	1.51997	3/20/2001	03:34			
8/1.3	UWE Bristol	Oil B 589nm	66.11(60)	65.22	1.52012	1.52012	3/20/2001	03:34			
8/1.4	UWE Bristol	Oil B 589nm	66.00(70)	65.125	1.52015	1.52015	3/20/2001	03:34			
9/1.1	UWE Bristol	Oil B 589nm	66.12(86)	65.195	1.52013	1.52013	3/20/2001	03:42			
9/1.2	UWE Bristol	Oil B 589nm	66.02(34)	65.075	1.52017	1.52017	3/20/2001	03:42			
9/1.3	UWE Bristol	Oil B 589nm	65.97(4)	65.005	1.5202	1.52020	3/20/2001	03:42			
9/1.4	UWE Bristol	Oil B 589nm	65.89(5)	65.095	1.52016	1.52016	3/20/2001	03:42			
10/1.1	UWE Bristol	Oil B 589nm	65.84(54)	64.99	1.5202	1.52020	3/20/2001	03:52			
10/1.2	UWE Bristol	Oil B 589nm	66.34(17)	65.45	1.52003	1.52003	3/20/2001	03:52			
10/1.3	UWE Bristol	Oil B 589nm	65.92(37)	65.04	1.52018	1.52018	3/20/2001	03:52			
10/1.4	UWE Bristol	Oil B 589nm	66.09(48)	65.205	1.52012	1.52012	3/20/2001	03:52			
11/1.1	UWE Bristol	Oil B 589nm	66.30(8)	65.47	1.52002	1.52002	3/20/2001	04:01			
11/1.2	UWE Bristol	Oil B 589nm	66.09(3)	65.155	1.52014	1.52014	3/20/2001	04:01			
11/1.3	UWE Bristol	Oil B 589nm	66.17(7)	65.285	1.52009	1.52009	3/20/2001	04:01			
11/1.4	UWE Bristol	Oil B 589nm	66.05(3)	65.14	1.52015	1.52015	3/20/2001	04:01			
12/1.1	UWE Bristol	Oil B 589nm	66.09(6)	65.195	1.52013	1.52013	3/20/2001	04:10			
12/1.2	UWE Bristol	Oil B 589nm	65.98(27)	65.035	1.52019	1.52019	3/20/2001	04:10			
12/1.3	UWE Bristol	Oil B 589nm	65.84(30)	65.01	1.52019	1.52019	3/20/2001	04:10			
12/1.4	UWE Bristol	Oil B 589nm	66.00(39)	65.11	1.52016	1.52016	3/20/2001	04:10			
Mean of 48 Samples: 65.31				Range: 64.54 - 66.21		SD: 0.302					
				1.52008		Range: 1.51975 - 1.52036					
				SD: 0.0001108							
Control Sample AuBMW02: car, Float Toughened											
1/1.1	UWE Bristol	Oil B 589nm	66.34(99)	65.405	1.52005	1.52005	1/27/2009	15:11			

1/1.2	UWE Bristol	Oil B 589nm	66.32(99)	65.4	1.52005	1.52005	1/27/2009	15:11
1/1.3	UWE Bristol	Oil B 589nm	66.40(99)	65.47	1.52002	1.52002	1/27/2009	15:11
2/1.1	UWE Bristol	Oil B 589nm	66.31(99)	65.42	1.52004	1.52004	1/27/2009	15:18
2/1.2	UWE Bristol	Oil B 589nm	66.37(99)	65.465	1.52003	1.52003	1/27/2009	15:18
2/1.3	UWE Bristol	Oil B 589nm	66.09(99)	65.185	1.52013	1.52013	1/27/2009	15:18
2/1.4	UWE Bristol	Oil B 589nm	66.31(99)	65.415	1.52005	1.52005	1/27/2009	15:18
3/1.1	UWE Bristol	Oil B 589nm	66.15(99)	65.28	1.52009	1.52009	1/27/2009	15:26
3/1.2	UWE Bristol	Oil B 589nm	66.04(99)	65.155	1.52014	1.52014	1/27/2009	15:26
3/1.3	UWE Bristol	Oil B 589nm	66.32(99)	65.43	1.52004	1.52004	1/27/2009	15:26
3/1.4	UWE Bristol	Oil B 589nm	66.34(99)	65.475	1.52002	1.52002	1/27/2009	15:26
4/1.1	UWE Bristol	Oil B 589nm	65.94(99)	65.1	1.52016	1.52016	2/20/2009	12:34
4/1.2	UWE Bristol	Oil B 589nm	66.02(99)	65.18	1.52013	1.52013	2/20/2009	12:34
4/1.3	UWE Bristol	Oil B 589nm	65.87(99)	65.035	1.52019	1.52019	2/20/2009	12:34
4/1.4	UWE Bristol	Oil B 589nm	65.89(99)	65.05	1.52018	1.52018	2/20/2009	12:34
5/1.1	UWE Bristol	Oil B 589nm	65.69(55)	64.815	1.52027	1.52027	2/20/2009	12:43
5/1.2	UWE Bristol	Oil B 589nm	65.48(99)	64.6	1.52034	1.52034	2/20/2009	12:43
5/1.3	UWE Bristol	Oil B 589nm	65.52(99)	64.63	1.52033	1.52033	2/20/2009	12:43
5/1.4	UWE Bristol	Oil B 589nm	65.56(71)	64.675	1.52032	1.52032	2/20/2009	12:43
6/1.1	UWE Bristol	Oil B 589nm	65.57(99)	64.665	1.52032	1.52032	2/20/2009	12:56
6/1.2	UWE Bristol	Oil B 589nm	65.51(99)	64.6	1.52034	1.52034	2/20/2009	12:56
6/1.3	UWE Bristol	Oil B 589nm	65.57(93)	64.675	1.52032	1.52032	2/20/2009	12:56
6/1.4	UWE Bristol	Oil B 589nm	65.48(66)	64.57	1.52035	1.52035	2/20/2009	12:56
7/1.1	UWE Bristol	Oil B 589nm	65.86(99)	64.965	1.52021	1.52021	2/20/2009	13:08
7/1.2	UWE Bristol	Oil B 589nm	66.02(99)	65.115	1.52016	1.52016	2/20/2009	13:08
7/1.3	UWE Bristol	Oil B 589nm	66.00(56)	65.09	1.52016	1.52016	2/20/2009	13:08
7/1.4	UWE Bristol	Oil B 589nm	65.86(29)	64.95	1.52021	1.52021	2/20/2009	13:08
8/1.1	UWE Bristol	Oil B 589nm	65.79(99)	64.88	1.52024	1.52024	2/20/2009	13:27
8/1.2	UWE Bristol	Oil B 589nm	66.08(87)	65.155	1.52014	1.52014	2/20/2009	13:27
8/1.3	UWE Bristol	Oil B 589nm	66.07(68)	65.12	1.52015	1.52015	2/20/2009	13:27
8/1.4	UWE Bristol	Oil B 589nm	66.11(95)	65.19	1.52013	1.52013	2/20/2009	13:27

9/1.1	UWE Bristol	Oil B 589nm	65.91(99)	65	1.5202	1.52020	2/20/2009	13:50
9/1.2	UWE Bristol	Oil B 589nm	65.56(64)	64.67	1.52032	1.52032	2/20/2009	13:50
9/1.3	UWE Bristol	Oil B 589nm	66.05(81)	65.14	1.52015	1.52015	2/20/2009	13:50
9/1.4	UWE Bristol	Oil B 589nm	65.95(61)	65.05	1.52018	1.52018	2/20/2009	13:50
10/1.1	UWE Bristol	Oil B 589nm	65.84(31)	64.92	1.52023	1.52023	2/20/2009	14:03
10/1.2	UWE Bristol	Oil B 589nm	65.64(56)	64.75	1.52029	1.52029	2/20/2009	14:03
10/1.3	UWE Bristol	Oil B 589nm	65.75(66)	64.84	1.52025	1.52025	2/20/2009	14:03
10/1.4	UWE Bristol	Oil B 589nm	65.88(68)	65	1.5202	1.52020	2/20/2009	14:03
11/1.1	UWE Bristol	Oil B 589nm	66.13(36)	65.225	1.52012	1.52012	2/20/2009	14:11
11/1.2	UWE Bristol	Oil B 589nm	65.64(34)	64.74	1.52029	1.52029	2/20/2009	14:11
11/1.3	UWE Bristol	Oil B 589nm	65.80(63)	64.91	1.52023	1.52023	2/20/2009	14:11
11/1.4	UWE Bristol	Oil B 589nm	66.05(72)	65.14	1.52015	1.52015	2/20/2009	14:11
12/1.1	UWE Bristol	Oil B 589nm	66.00(99)	65.16	1.52014	1.52014	2/20/2009	14:18
12/1.2	UWE Bristol	Oil B 589nm	65.96(99)	65.125	1.52015	1.52015	2/20/2009	14:18
12/1.3	UWE Bristol	Oil B 589nm	65.97(99)	65.135	1.52015	1.52015	2/20/2009	14:18
12/1.4	UWE Bristol	Oil B 589nm	65.95(99)	65.105	1.52016	1.52016	2/20/2009	14:18

Mean of 47 Samples: 65.04 Range: 64.57 - 65.47 SD: 0.260
1.52018 Range: 1.52002 - 1.52035 SD: 0.0000949

Control Sample AUCIT02: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	60.43(94)	59.465	1.52223	1.52223	1/27/2009	11:24
1/1.2	UWE Bristol	Oil B 589nm	60.40(96)	59.435	1.52224	1.52224	1/27/2009	11:24
1/1.3	UWE Bristol	Oil B 589nm	60.29(99)	59.325	1.52228	1.52228	1/27/2009	11:24
1/1.4	UWE Bristol	Oil B 589nm	60.40(99)	59.435	1.52224	1.52224	1/27/2009	11:24
2/1.1	UWE Bristol	Oil B 589nm	60.38(99)	59.475	1.52222	1.52222	1/27/2009	11:40
2/1.2	UWE Bristol	Oil B 589nm	60.40(99)	59.485	1.52222	1.52222	1/27/2009	11:40
2/1.3	UWE Bristol	Oil B 589nm	60.42(99)	59.505	1.52221	1.52221	1/27/2009	11:40
2/1.4	UWE Bristol	Oil B 589nm	60.42(99)	59.51	1.52221	1.52221	1/27/2009	11:40
3/1.1	UWE Bristol	Oil B 589nm	60.32(99)	59.49	1.52222	1.52222	1/27/2009	11:54
3/1.2	UWE Bristol	Oil B 589nm	60.36(99)	59.54	1.5222	1.52220	1/27/2009	11:54

3/1.3	UWE Bristol	Oil B 589nm	60.32(99)	59.495	1.52222	1.52222	1/27/2009	11:54
3/1.4	UWE Bristol	Oil B 589nm	60.28(99)	59.45	1.52223	1.52223	1/27/2009	11:54
4/1.1	UWE Bristol	Oil B 589nm	60.17(42)	59.21	1.52232	1.52232	2/18/2009	13:57
4/1.2	UWE Bristol	Oil B 589nm	59.84(37)	58.88	1.52244	1.52244	2/18/2009	13:57
4/1.3	UWE Bristol	Oil B 589nm	59.95(52)	58.98	1.5224	1.52240	2/18/2009	13:57
4/1.4	UWE Bristol	Oil B 589nm	59.97(54)	59	1.52239	1.52239	2/18/2009	13:57
5/1.1	UWE Bristol	Oil B 589nm	60.56(99)	59.58	1.52218	1.52218	2/18/2009	14:05
5/1.2	UWE Bristol	Oil B 589nm	60.76(99)	59.795	1.52211	1.52211	2/18/2009	14:05
5/1.3	UWE Bristol	Oil B 589nm	60.76(99)	59.8	1.5221	1.52210	2/18/2009	14:05
5/1.4	UWE Bristol	Oil B 589nm	60.62(99)	59.67	1.52215	1.52215	2/18/2009	14:05
6/1.1	UWE Bristol	Oil B 589nm	60.09(77)	59.165	1.52234	1.52234	2/18/2009	14:14
6/1.2	UWE Bristol	Oil B 589nm	59.99(99)	59.085	1.52237	1.52237	2/18/2009	14:14
6/1.3	UWE Bristol	Oil B 589nm	59.89(99)	58.97	1.52241	1.52241	2/18/2009	14:14
6/1.4	UWE Bristol	Oil B 589nm	60.10(99)	59.19	1.52232	1.52232	2/18/2009	14:14
7/1.1	UWE Bristol	Oil B 589nm	60.35(46)	59.385	1.52226	1.52226	2/18/2009	14:23
7/1.2	UWE Bristol	Oil B 589nm	60.21(56)	59.23	1.52231	1.52231	2/18/2009	14:23
7/1.3	UWE Bristol	Oil B 589nm	60.06(50)	59.215	1.52232	1.52232	2/18/2009	14:23
7/1.4	UWE Bristol	Oil B 589nm	59.87(80)	59.395	1.52225	1.52225	2/18/2009	14:23
8/1.1	UWE Bristol	Oil B 589nm	60.25(74)	59.285	1.52229	1.52229	2/18/2009	14:32
8/1.2	UWE Bristol	Oil B 589nm	60.27(63)	59.26	1.5223	1.52230	2/18/2009	14:32
8/1.3	UWE Bristol	Oil B 589nm	60.16(61)	59.17	1.52233	1.52233	2/18/2009	14:32
8/1.4	UWE Bristol	Oil B 589nm	60.56(45)	59.55	1.52219	1.52219	2/18/2009	14:32
9/1.1	UWE Bristol	Oil B 589nm	60.61(96)	59.68	1.52215	1.52215	2/18/2009	14:44
9/1.2	UWE Bristol	Oil B 589nm	60.55(94)	59.65	1.52216	1.52216	2/18/2009	14:44
9/1.3	UWE Bristol	Oil B 589nm	60.59(75)	59.675	1.52215	1.52215	2/18/2009	14:44
9/1.4	UWE Bristol	Oil B 589nm	60.49(68)	59.605	1.52217	1.52217	2/18/2009	14:44
10/1.1	UWE Bristol	Oil B 589nm	60.77(99)	59.805	1.5221	1.52210	2/18/2009	14:53
10/1.2	UWE Bristol	Oil B 589nm	60.73(99)	59.785	1.52211	1.52211	2/18/2009	14:53
10/1.3	UWE Bristol	Oil B 589nm	60.69(99)	59.73	1.52213	1.52213	2/18/2009	14:53
10/1.4	UWE Bristol	Oil B 589nm	60.74(99)	59.79	1.52211	1.52211	2/18/2009	14:53

11/1.1	UWE Bristol	Oil B 589nm	60.26(54)	59.28	1.52229	1.52229	2/18/2009	15:11
11/1.2	UWE Bristol	Oil B 589nm	60.24(88)	59.24	1.52231	1.52231	2/18/2009	15:11
11/1.3	UWE Bristol	Oil B 589nm	60.20(99)	59.205	1.52232	1.52232	2/18/2009	15:11
11/1.4	UWE Bristol	Oil B 589nm	60.33(50)	59.305	1.52228	1.52228	2/18/2009	15:11
12/1.1	UWE Bristol	Oil B 589nm	60.41(99)	59.44	1.52223	1.52223	2/18/2009	15:21
12/1.2	UWE Bristol	Oil B 589nm	60.38(99)	59.41	1.52224	1.52224	2/18/2009	15:21
12/1.3	UWE Bristol	Oil B 589nm	60.38(99)	59.395	1.52225	1.52225	2/18/2009	15:21
12/1.4	UWE Bristol	Oil B 589nm	60.35(99)	59.36	1.52226	1.52226	2/18/2009	15:21
Mean of 48 Samples: 59.41 Range: 58.88 - 59.81 SD: 0.234								
1.52225 Range: 1.52210 - 1.52244 SD: 0.0000852								

Control Sample AuFIA02: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	71.42(57)	70.585	1.51815	1.51815	3/20/2001	04:20
1/1.2	UWE Bristol	Oil B 589nm	71.77(35)	70.95	1.51802	1.51802	3/20/2001	04:20
1/1.3	UWE Bristol	Oil B 589nm	71.57(79)	70.72	1.5181	1.51810	3/20/2001	04:20
1/1.4	UWE Bristol	Oil B 589nm	71.57(43)	70.73	1.5181	1.51810	3/20/2001	04:20
2/1.1	UWE Bristol	Oil B 589nm	71.64(19)	70.825	1.51806	1.51806	3/20/2001	04:28
2/1.2	UWE Bristol	Oil B 589nm	71.90(19)	71.035	1.51799	1.51799	3/20/2001	04:28
2/1.3	UWE Bristol	Oil B 589nm	71.70(70)	70.92	1.51803	1.51803	3/20/2001	04:28
2/1.4	UWE Bristol	Oil B 589nm	71.62(16)	70.77	1.51808	1.51808	3/20/2001	04:28
3/1.1	UWE Bristol	Oil B 589nm	71.65(52)	70.815	1.51807	1.51807	3/20/2001	04:35
3/1.2	UWE Bristol	Oil B 589nm	71.50(52)	70.665	1.51812	1.51812	3/20/2001	04:35
3/1.3	UWE Bristol	Oil B 589nm	71.73(99)	70.91	1.51803	1.51803	3/20/2001	04:35
3/1.4	UWE Bristol	Oil B 589nm	71.62(69)	70.78	1.51808	1.51808	3/20/2001	04:35
4/1.1	UWE Bristol	Oil B 589nm	71.54(30)	70.66	1.51812	1.51812	3/20/2001	04:42
4/1.2	UWE Bristol	Oil B 589nm	71.63(71)	70.75	1.51809	1.51809	3/20/2001	04:42
4/1.3	UWE Bristol	Oil B 589nm	71.71(99)	70.845	1.51806	1.51806	3/20/2001	04:42
4/1.4	UWE Bristol	Oil B 589nm	71.77(85)	70.93	1.51802	1.51802	3/20/2001	04:42
5/1.1	UWE Bristol	Oil B 589nm	71.65(80)	70.805	1.51807	1.51807	3/20/2001	04:49
5/1.2	UWE Bristol	Oil B 589nm	71.68(99)	70.81	1.51807	1.51807	3/20/2001	04:49

5/1.3	UWE Bristol	Oil B 589nm	71.75(99)	70.865	1.51805	1.51805	3/20/2001	04:49
5/1.4	UWE Bristol	Oil B 589nm	71.56(56)	70.675	1.51812	1.51812	3/20/2001	04:49
6/1.1	UWE Bristol	Oil B 589nm	71.60(92)	70.755	1.51809	1.51809	3/20/2001	04:57
6/1.2	UWE Bristol	Oil B 589nm	71.62(95)	70.78	1.51808	1.51808	3/20/2001	04:57
6/1.3	UWE Bristol	Oil B 589nm	71.58(99)	70.74	1.51809	1.51809	3/20/2001	04:57
6/1.4	UWE Bristol	Oil B 589nm	71.55(85)	70.695	1.51811	1.51811	3/20/2001	04:57
7/1.1	UWE Bristol	Oil B 589nm	71.60(99)	70.775	1.51808	1.51808	3/20/2001	05:05
7/1.2	UWE Bristol	Oil B 589nm	71.52(99)	70.695	1.51811	1.51811	3/20/2001	05:05
7/1.3	UWE Bristol	Oil B 589nm	71.55(99)	70.725	1.5181	1.51810	3/20/2001	05:05
7/1.4	UWE Bristol	Oil B 589nm	71.44(99)	70.605	1.51814	1.51814	3/20/2001	05:05
8/1.1	UWE Bristol	Oil B 589nm	71.63(34)	70.9	1.51803	1.51803	3/20/2001	05:17
8/1.2	UWE Bristol	Oil B 589nm	71.71(46)	70.865	1.51805	1.51805	3/20/2001	05:17
8/1.3	UWE Bristol	Oil B 589nm	71.77(32)	70.935	1.51802	1.51802	3/20/2001	05:17
8/1.4	UWE Bristol	Oil B 589nm	71.75(49)	70.925	1.51803	1.51803	3/20/2001	05:17
9/1.1	UWE Bristol	Oil B 589nm	71.69(43)	70.805	1.51807	1.51807	3/20/2001	05:25
9/1.2	UWE Bristol	Oil B 589nm	71.88(99)	70.93	1.51802	1.51802	3/20/2001	05:25
9/1.3	UWE Bristol	Oil B 589nm	71.76(99)	70.82	1.51806	1.51806	3/20/2001	05:25
9/1.4	UWE Bristol	Oil B 589nm	71.90(32)	70.96	1.51801	1.51801	3/20/2001	05:25
10/1.1	UWE Bristol	Oil B 589nm	71.52(66)	70.695	1.51811	1.51811	3/20/2001	05:33
10/1.2	UWE Bristol	Oil B 589nm	71.61(66)	70.77	1.51808	1.51808	3/20/2001	05:33
10/1.3	UWE Bristol	Oil B 589nm	71.65(55)	70.81	1.51807	1.51807	3/20/2001	05:33
10/1.4	UWE Bristol	Oil B 589nm	71.48(37)	70.63	1.51813	1.51813	3/20/2001	05:33
11/1.1	UWE Bristol	Oil B 589nm	71.97(72)	71.12	1.51795	1.51795	3/20/2001	05:41
11/1.2	UWE Bristol	Oil B 589nm	71.98(98)	71.145	1.51795	1.51795	3/20/2001	05:41
11/1.3	UWE Bristol	Oil B 589nm	72.01(99)	71.165	1.51794	1.51794	3/20/2001	05:41
11/1.4	UWE Bristol	Oil B 589nm	72.04(86)	71.175	1.51794	1.51794	3/20/2001	05:41
12/1.1	UWE Bristol	Oil B 589nm	71.64(37)	70.785	1.51808	1.51808	3/20/2001	05:47
12/1.2	UWE Bristol	Oil B 589nm	71.80(23)	70.905	1.51803	1.51803	3/20/2001	05:47
12/1.3	UWE Bristol	Oil B 589nm	71.62(99)	70.78	1.51808	1.51808	3/20/2001	05:47
12/1.4	UWE Bristol	Oil B 589nm	71.65(91)	70.795	1.51807	1.51807	3/20/2001	05:47

Mean of 48 Samples: 70.83 Range: 70.58 - 71.18 SD: 0.138
 1.51806 Range: 1.51794 - 1.51815 SD: 0.0000500

Control Sample AuFOR01: car, Float Laminated

1/1.1	UWE Bristol	Oil B 589nm	64.70(60)	63.82	1.52063	1.52063	2/22/2001	03:37
1/1.2	UWE Bristol	Oil B 589nm	64.62(51)	63.765	1.52065	1.52065	2/22/2001	03:37
1/1.3	UWE Bristol	Oil B 589nm	64.54(37)	63.67	1.52068	1.52068	2/22/2001	03:37
1/1.4	UWE Bristol	Oil B 589nm	64.34(27)	63.49	1.52075	1.52075	2/22/2001	03:37
2/1.1	UWE Bristol	Oil B 589nm	64.92(41)	64.11	1.52052	1.52052	2/22/2001	03:45
2/1.2	UWE Bristol	Oil B 589nm	64.92(37)	64.085	1.52053	1.52053	2/22/2001	03:45
2/1.3	UWE Bristol	Oil B 589nm	64.43(49)	63.68	1.52068	1.52068	2/22/2001	03:45
2/1.4	UWE Bristol	Oil B 589nm	64.89(42)	64.06	1.52054	1.52054	2/22/2001	03:45
3/1.1	UWE Bristol	Oil B 589nm	64.84(20)	63.96	1.52058	1.52058	2/22/2001	03:58
3/1.2	UWE Bristol	Oil B 589nm	64.25(53)	63.44	1.52077	1.52077	2/22/2001	03:58
3/1.3	UWE Bristol	Oil B 589nm	64.50(80)	63.65	1.52069	1.52069	2/22/2001	03:58
3/1.4	UWE Bristol	Oil B 589nm	64.71(47)	63.865	1.52061	1.52061	2/22/2001	03:58
4/1.1	UWE Bristol	Oil B 589nm	64.86(22)	63.965	1.52058	1.52058	2/22/2001	04:10
4/1.2	UWE Bristol	Oil B 589nm	64.88(58)	63.965	1.52058	1.52058	2/22/2001	04:10
4/1.3	UWE Bristol	Oil B 589nm	64.76(57)	63.87	1.52061	1.52061	2/22/2001	04:10
4/1.4	UWE Bristol	Oil B 589nm	64.83(57)	63.94	1.52058	1.52058	2/22/2001	04:10
5/1.1	UWE Bristol	Oil B 589nm	64.78(99)	63.88	1.52061	1.52061	2/22/2001	04:19
5/1.2	UWE Bristol	Oil B 589nm	64.84(99)	63.95	1.52058	1.52058	2/22/2001	04:19
5/1.3	UWE Bristol	Oil B 589nm	64.95(94)	64.03	1.52055	1.52055	2/22/2001	04:19
5/1.4	UWE Bristol	Oil B 589nm	64.98(56)	64.065	1.52054	1.52054	2/22/2001	04:19
6/1.1	UWE Bristol	Oil B 589nm	64.95(10)	64.02	1.52056	1.52056	2/22/2001	04:26
6/1.2	UWE Bristol	Oil B 589nm	64.79(31)	63.885	1.52061	1.52061	2/22/2001	04:26
6/1.3	UWE Bristol	Oil B 589nm	65.03(48)	64.115	1.52052	1.52052	2/22/2001	04:26
6/1.4	UWE Bristol	Oil B 589nm	64.97(48)	64.04	1.52055	1.52055	2/22/2001	04:26
7/1.1	UWE Bristol	Oil B 589nm	64.97(99)	64.105	1.52053	1.52053	2/22/2001	04:39
7/1.2	UWE Bristol	Oil B 589nm	64.77(99)	63.885	1.52061	1.52061	2/22/2001	04:39

7/1.3	UWE Bristol	Oil B 589nm	64.88(95)	63.985	1.52057	1.52057	2/22/2001	04:39
7/1.4	UWE Bristol	Oil B 589nm	64.93(99)	64.01	1.52056	1.52056	2/22/2001	04:39
8/1.1	UWE Bristol	Oil B 589nm	65.06(99)	64.175	1.5205	1.52050	2/22/2001	04:47
8/1.2	UWE Bristol	Oil B 589nm	65.03(99)	64.145	1.52051	1.52051	2/22/2001	04:47
8/1.3	UWE Bristol	Oil B 589nm	65.02(99)	64.14	1.52051	1.52051	2/22/2001	04:47
8/1.4	UWE Bristol	Oil B 589nm	65.11(31)	64.22	1.52048	1.52048	2/22/2001	04:47
9/1.1	UWE Bristol	Oil B 589nm	65.04(99)	64.155	1.52051	1.52051	2/22/2001	04:54
9/1.2	UWE Bristol	Oil B 589nm	65.08(69)	64.185	1.5205	1.52050	2/22/2001	04:54
9/1.3	UWE Bristol	Oil B 589nm	65.06(75)	64.19	1.52049	1.52049	2/22/2001	04:54
9/1.4	UWE Bristol	Oil B 589nm	65.04(61)	64.115	1.52052	1.52052	2/22/2001	04:54
10/1.1	UWE Bristol	Oil B 589nm	64.94(38)	64.12	1.52052	1.52052	2/22/2001	05:03
10/1.2	UWE Bristol	Oil B 589nm	64.83(49)	64	1.52056	1.52056	2/22/2001	05:03
10/1.3	UWE Bristol	Oil B 589nm	64.83(58)	63.985	1.52057	1.52057	2/22/2001	05:03
10/1.4	UWE Bristol	Oil B 589nm	64.84(36)	64.045	1.52055	1.52055	2/22/2001	05:03
11/1.1	UWE Bristol	Oil B 589nm	64.64(11)	63.735	1.52066	1.52066	2/22/2001	05:15
11/1.2	UWE Bristol	Oil B 589nm	64.98(26)	64.15	1.52051	1.52051	2/22/2001	05:15
11/1.3	UWE Bristol	Oil B 589nm	64.98(21)	64.15	1.52051	1.52051	2/22/2001	05:15
11/1.4	UWE Bristol	Oil B 589nm	65.25(18)	64.44	1.5204	1.52040	2/22/2001	05:15
12/1.1	UWE Bristol	Oil B 589nm	64.96(9)	64.105	1.52053	1.52053	2/22/2001	05:28
12/1.2	UWE Bristol	Oil B 589nm	64.95(24)	64.115	1.52052	1.52052	2/22/2001	05:28
12/1.3	UWE Bristol	Oil B 589nm	65.04(13)	64.25	1.52047	1.52047	2/22/2001	05:28
12/1.4	UWE Bristol	Oil B 589nm	64.81(13)	64.005	1.52056	1.52056	2/22/2001	05:28

Mean of 48 Samples: 63.99 Range: 63.44 - 64.44 SD: 0.192
1.52057 Range: 1.52040 - 1.52077 SD: 0.0000705

Control Sample AuFOR02: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	67.23(48)	66.265	1.51973	1.51973	2/22/2001	01:38
1/1.2	UWE Bristol	Oil B 589nm	66.93(86)	66.005	1.51983	1.51983	2/22/2001	01:38
1/1.3	UWE Bristol	Oil B 589nm	67.36(87)	66.42	1.51968	1.51968	2/22/2001	01:38
1/1.4	UWE Bristol	Oil B 589nm	67.73(47)	66.8	1.51954	1.51954	2/22/2001	01:38

2/1.1	UWE Bristol	Oil B 589nm	67.00(64)	66.04	1.51982	1.51982	2/22/2001	01:45
2/1.2	UWE Bristol	Oil B 589nm	67.09(35)	66.13	1.51978	1.51978	2/22/2001	01:45
2/1.3	UWE Bristol	Oil B 589nm	67.33(99)	66.405	1.51968	1.51968	2/22/2001	01:45
2/1.4	UWE Bristol	Oil B 589nm	67.07(99)	66.145	1.51978	1.51978	2/22/2001	01:45
3/1.1	UWE Bristol	Oil B 589nm	67.12(32)	66.195	1.51976	1.51976	2/22/2001	01:51
3/1.2	UWE Bristol	Oil B 589nm	67.13(42)	66.265	1.51973	1.51973	2/22/2001	01:51
3/1.3	UWE Bristol	Oil B 589nm	67.09(99)	66.2	1.51976	1.51976	2/22/2001	01:51
3/1.4	UWE Bristol	Oil B 589nm	67.13(37)	66.235	1.51975	1.51975	2/22/2001	01:51
4/1.1	UWE Bristol	Oil B 589nm	66.97(90)	66.115	1.51979	1.51979	2/22/2001	02:02
4/1.2	UWE Bristol	Oil B 589nm	66.89(99)	66.01	1.51983	1.51983	2/22/2001	02:02
4/1.3	UWE Bristol	Oil B 589nm	66.95(99)	66.05	1.51981	1.51981	2/22/2001	02:02
4/1.4	UWE Bristol	Oil B 589nm	67.00(75)	66.115	1.51979	1.51979	2/22/2001	02:02
5/1.1	UWE Bristol	Oil B 589nm	67.08(99)	66.2	1.51976	1.51976	2/22/2001	02:11
5/1.2	UWE Bristol	Oil B 589nm	67.12(99)	66.23	1.51975	1.51975	2/22/2001	02:11
5/1.3	UWE Bristol	Oil B 589nm	67.09(52)	66.215	1.51975	1.51975	2/22/2001	02:11
5/1.4	UWE Bristol	Oil B 589nm	67.40(14)	66.525	1.51964	1.51964	2/22/2001	02:11
6/1.1	UWE Bristol	Oil B 589nm	66.94(12)	65.99	1.51983	1.51983	2/22/2001	02:20
6/1.2	UWE Bristol	Oil B 589nm	66.82(20)	65.945	1.51985	1.51985	2/22/2001	02:20
6/1.3	UWE Bristol	Oil B 589nm	67.05(22)	66.105	1.51979	1.51979	2/22/2001	02:20
6/1.4	UWE Bristol	Oil B 589nm	67.17(54)	66.265	1.51973	1.51973	2/22/2001	02:20
7/1.1	UWE Bristol	Oil B 589nm	66.90(32)	66.06	1.51981	1.51981	2/22/2001	02:34
7/1.2	UWE Bristol	Oil B 589nm	66.83(53)	66.005	1.51983	1.51983	2/22/2001	02:34
7/1.3	UWE Bristol	Oil B 589nm	67.20(47)	66.37	1.51969	1.51969	2/22/2001	02:34
7/1.4	UWE Bristol	Oil B 589nm	67.22(14)	66.35	1.5197	1.51970	2/22/2001	02:34
8/1.1	UWE Bristol	Oil B 589nm	66.98(99)	66.13	1.51978	1.51978	2/22/2001	02:45
8/1.2	UWE Bristol	Oil B 589nm	67.03(99)	66.17	1.51977	1.51977	2/22/2001	02:45
8/1.3	UWE Bristol	Oil B 589nm	66.98(64)	66.14	1.51978	1.51978	2/22/2001	02:45
8/1.4	UWE Bristol	Oil B 589nm	67.03(39)	66.18	1.51976	1.51976	2/22/2001	02:45
9/1.1	UWE Bristol	Oil B 589nm	67.28(70)	66.485	1.51965	1.51965	2/22/2001	02:51
9/1.2	UWE Bristol	Oil B 589nm	67.28(99)	66.5	1.51965	1.51965	2/22/2001	02:51

9/1.3	UWE Bristol	Oil B 589nm	67.31(6)	66.445	1.51967	1.51967	2/22/2001	02:51
9/1.4	UWE Bristol	Oil B 589nm	67.04(42)	66.275	1.51973	1.51973	2/22/2001	02:51
10/1.1	UWE Bristol	Oil B 589nm	66.94(40)	66.125	1.51979	1.51979	2/22/2001	03:02
10/1.2	UWE Bristol	Oil B 589nm	66.95(30)	66.125	1.51979	1.51979	2/22/2001	03:02
10/1.3	UWE Bristol	Oil B 589nm	66.98(80)	66.18	1.51976	1.51976	2/22/2001	03:02
10/1.4	UWE Bristol	Oil B 589nm	67.16(58)	66.345	1.51971	1.51971	2/22/2001	03:02
11/1.1	UWE Bristol	Oil B 589nm	67.48(8)	66.635	1.5196	1.51960	2/22/2001	03:11
11/1.2	UWE Bristol	Oil B 589nm	67.03(37)	66.255	1.51974	1.51974	2/22/2001	03:11
11/1.3	UWE Bristol	Oil B 589nm	67.15(57)	66.365	1.5197	1.51970	2/22/2001	03:11
11/1.4	UWE Bristol	Oil B 589nm	67.34(52)	66.545	1.51963	1.51963	2/22/2001	03:11
12/1.1	UWE Bristol	Oil B 589nm	67.25(58)	66.38	1.51969	1.51969	2/22/2001	03:20
12/1.2	UWE Bristol	Oil B 589nm	67.08(61)	66.205	1.51976	1.51976	2/22/2001	03:20
12/1.3	UWE Bristol	Oil B 589nm	67.13(89)	66.265	1.51973	1.51973	2/22/2001	03:20
12/1.4	UWE Bristol	Oil B 589nm	67.06(79)	66.215	1.51975	1.51975	2/22/2001	03:20

Mean of 48 Samples: 66.24 Range: 65.94 - 66.80 SD: 0.178
1.51974 Range: 1.51954 - 1.51985 SD: 0.0000650

Control Sample AuFOR03: car, Float Toughened, Colourless

1/1.1	UWE Bristol	Oil B 589nm	76.32(75)	75.345	1.51641	1.51641	2/19/2001	01:46
1/1.2	UWE Bristol	Oil B 589nm	76.31(30)	75.365	1.5164	1.51640	2/19/2001	01:46
1/1.3	UWE Bristol	Oil B 589nm	76.48(44)	75.535	1.51634	1.51634	2/19/2001	01:46
1/1.4	UWE Bristol	Oil B 589nm	76.05(61)	75.125	1.51649	1.51649	2/19/2001	01:46
2/1.1	UWE Bristol	Oil B 589nm	75.95(26)	75.115	1.51649	1.51649	2/19/2001	01:55
2/1.2	UWE Bristol	Oil B 589nm	76.38(76)	75.53	1.51634	1.51634	2/19/2001	01:55
2/1.3	UWE Bristol	Oil B 589nm	76.70(12)	75.65	1.51629	1.51629	2/19/2001	01:55
2/1.4	UWE Bristol	Oil B 589nm	76.81(24)	75.795	1.51624	1.51624	2/19/2001	01:55
3/1.1	UWE Bristol	Oil B 589nm	76.13(61)	75.125	1.51649	1.51649	2/19/2001	02:20
3/1.2	UWE Bristol	Oil B 589nm	75.33(44)	74.29	1.51679	1.51679	2/19/2001	02:20
3/1.3	UWE Bristol	Oil B 589nm	76.28(44)	75.255	1.51644	1.51644	2/19/2001	02:20
3/1.4	UWE Bristol	Oil B 589nm	73.13(24)	72.14	1.51758	1.51758	2/19/2001	02:20

4/1.1	UWE Bristol	Oil B 589nm	76.15(25)	75.225	1.51645	1.51645	2/19/2001	02:44
4/1.2	UWE Bristol	Oil B 589nm	76.23(42)	75.27	1.51643	1.51643	2/19/2001	02:44
4/1.3	UWE Bristol	Oil B 589nm	76.23(98)	75.285	1.51643	1.51643	2/19/2001	02:44
4/1.4	UWE Bristol	Oil B 589nm	76.23(99)	75.29	1.51643	1.51643	2/19/2001	02:44
5/1.1	UWE Bristol	Oil B 589nm	76.30(57)	75.35	1.5164	1.51640	2/19/2001	02:51
5/1.2	UWE Bristol	Oil B 589nm	76.30(96)	75.375	1.5164	1.51640	2/19/2001	02:51
5/1.3	UWE Bristol	Oil B 589nm	76.28(99)	75.375	1.5164	1.51640	2/19/2001	02:51
5/1.4	UWE Bristol	Oil B 589nm	76.30(99)	75.41	1.51638	1.51638	2/19/2001	02:51
6/1.1	UWE Bristol	Oil B 589nm	76.33(52)	75.405	1.51639	1.51639	2/19/2001	03:08
6/1.2	UWE Bristol	Oil B 589nm	76.35(9)	75.475	1.51636	1.51636	2/19/2001	03:08
6/1.3	UWE Bristol	Oil B 589nm	76.10(21)	75.25	1.51644	1.51644	2/19/2001	03:08
6/1.4	UWE Bristol	Oil B 589nm	76.14(16)	75.305	1.51642	1.51642	2/19/2001	03:08
7/1.1	UWE Bristol	Oil B 589nm	75.64(10)	74.98	1.51654	1.51654	2/19/2001	03:18
7/1.2	UWE Bristol	Oil B 589nm	76.25(18)	75.59	1.51632	1.51632	2/19/2001	03:18
7/1.3	UWE Bristol	Oil B 589nm	76.13(26)	75.35	1.5164	1.51640	2/19/2001	03:18
7/1.4	UWE Bristol	Oil B 589nm	75.96(9)	75.215	1.51646	1.51646	2/19/2001	03:18
8/1.1	UWE Bristol	Oil B 589nm	76.19(32)	75.345	1.51641	1.51641	2/19/2001	03:25
8/1.2	UWE Bristol	Oil B 589nm	76.23(47)	75.375	1.5164	1.51640	2/19/2001	03:25
8/1.3	UWE Bristol	Oil B 589nm	75.56(99)	74.71	1.51664	1.51664	2/19/2001	03:25
8/1.4	UWE Bristol	Oil B 589nm	75.79(70)	74.965	1.51655	1.51655	2/19/2001	03:25
9/1.1	UWE Bristol	Oil B 589nm	75.94(23)	75.115	1.51649	1.51649	2/19/2001	03:32
9/1.2	UWE Bristol	Oil B 589nm	76.27(16)	75.305	1.51642	1.51642	2/19/2001	03:32
9/1.3	UWE Bristol	Oil B 589nm	76.07(53)	75.26	1.51644	1.51644	2/19/2001	03:32
9/1.4	UWE Bristol	Oil B 589nm	76.07(49)	75.27	1.51643	1.51643	2/19/2001	03:32
10/1.1	UWE Bristol	Oil B 589nm	76.50(68)	75.59	1.51632	1.51632	2/19/2001	03:40
10/1.2	UWE Bristol	Oil B 589nm	76.30(33)	75.4	1.51639	1.51639	2/19/2001	03:40
10/1.3	UWE Bristol	Oil B 589nm	76.40(76)	75.54	1.51633	1.51633	2/19/2001	03:40
10/1.4	UWE Bristol	Oil B 589nm	76.04(5)	75.23	1.51645	1.51645	2/19/2001	03:40
11/1.1	UWE Bristol	Oil B 589nm	76.45(38)	75.71	1.51627	1.51627	2/19/2001	03:46
11/1.2	UWE Bristol	Oil B 589nm	76.47(77)	75.54	1.51633	1.51633	2/19/2001	03:46

11/1.3	UWE Bristol	Oil B 589nm	76.40(20)	75.44	1.51637	1.51637	2/19/2001	03:46
11/1.4	UWE Bristol	Oil B 589nm	76.38(99)	75.46	1.51636	1.51636	2/19/2001	03:46
12/1.1	UWE Bristol	Oil B 589nm	76.15(64)	75.17	1.51647	1.51647	2/19/2001	03:55
12/1.2	UWE Bristol	Oil B 589nm	76.15(53)	75.16	1.51647	1.51647	2/19/2001	03:55
12/1.3	UWE Bristol	Oil B 589nm	76.15(64)	75.205	1.51646	1.51646	2/19/2001	03:55
12/1.4	UWE Bristol	Oil B 589nm	76.17(44)	75.2	1.51646	1.51646	2/19/2001	03:55

Mean of 48 Samples: 75.24 Range: 72.14 - 75.79 SD: 0.514
1.51645 Range: 1.51624 - 1.51758 SD: 0.0001881

Control Sample AuFOR04: car, Float Toughened, Colourless

1/1.1	UWE Bristol	Oil B 589nm	76.30(99)	75.39	1.51639	1.51639	2/19/2001	04:06
1/1.2	UWE Bristol	Oil B 589nm	76.70(46)	75.75	1.51626	1.51626	2/19/2001	04:06
1/1.3	UWE Bristol	Oil B 589nm	76.66(53)	75.71	1.51627	1.51627	2/19/2001	04:06
1/1.4	UWE Bristol	Oil B 589nm	76.55(67)	75.345	1.51641	1.51641	2/19/2001	04:06
2/1.1	UWE Bristol	Oil B 589nm	75.29(17)	74.425	1.51675	1.51675	2/19/2001	04:13
2/1.2	UWE Bristol	Oil B 589nm	76.73(14)	75.815	1.51624	1.51624	2/19/2001	04:13
2/1.3	UWE Bristol	Oil B 589nm	76.81(56)	75.885	1.51621	1.51621	2/19/2001	04:13
2/1.4	UWE Bristol	Oil B 589nm	76.71(99)	75.81	1.51624	1.51624	2/19/2001	04:13
3/1.1	UWE Bristol	Oil B 589nm	76.90(23)	75.955	1.51618	1.51618	2/19/2001	04:20
3/1.2	UWE Bristol	Oil B 589nm	76.52(44)	75.52	1.51634	1.51634	2/19/2001	04:20
3/1.3	UWE Bristol	Oil B 589nm	76.77(41)	75.87	1.51621	1.51621	2/19/2001	04:20
3/1.4	UWE Bristol	Oil B 589nm	76.75(99)	75.85	1.51622	1.51622	2/19/2001	04:20
4/1.1	UWE Bristol	Oil B 589nm	76.50(45)	75.535	1.51634	1.51634	2/19/2001	04:32
4/1.2	UWE Bristol	Oil B 589nm	76.73(62)	75.785	1.51625	1.51625	2/19/2001	04:32
4/1.3	UWE Bristol	Oil B 589nm	76.63(99)	75.705	1.51628	1.51628	2/19/2001	04:32
4/1.4	UWE Bristol	Oil B 589nm	76.56(99)	75.63	1.5163	1.51630	2/19/2001	04:32
5/1.1	UWE Bristol	Oil B 589nm	76.25(17)	75.225	1.51645	1.51645	2/19/2001	04:39
5/1.2	UWE Bristol	Oil B 589nm	76.54(43)	75.61	1.51631	1.51631	2/19/2001	04:39
5/1.3	UWE Bristol	Oil B 589nm	76.53(37)	75.545	1.51633	1.51633	2/19/2001	04:39
5/1.4	UWE Bristol	Oil B 589nm	76.54(26)	75.52	1.51634	1.51634	2/19/2001	04:39

6/1.1	UWE Bristol	Oil B 589nm	76.45(49)	75.535	1.51634	1.51634	2/19/2001	04:46
6/1.2	UWE Bristol	Oil B 589nm	76.57(32)	75.66	1.51629	1.51629	2/19/2001	04:46
6/1.3	UWE Bristol	Oil B 589nm	76.65(86)	75.745	1.51626	1.51626	2/19/2001	04:46
6/1.4	UWE Bristol	Oil B 589nm	76.61(66)	75.705	1.51628	1.51628	2/19/2001	04:46
7/1.1	UWE Bristol	Oil B 589nm	76.50(99)	75.63	1.5163	1.51630	2/19/2001	04:55
7/1.2	UWE Bristol	Oil B 589nm	76.60(99)	75.715	1.51627	1.51627	2/19/2001	04:55
7/1.3	UWE Bristol	Oil B 589nm	76.57(99)	75.68	1.51628	1.51628	2/19/2001	04:55
7/1.4	UWE Bristol	Oil B 589nm	76.58(99)	75.49	1.51635	1.51635	2/19/2001	04:55
8/1.1	UWE Bristol	Oil B 589nm	76.42(89)	75.565	1.51633	1.51633	2/19/2001	05:02
8/1.2	UWE Bristol	Oil B 589nm	76.64(99)	75.775	1.51625	1.51625	2/19/2001	05:02
8/1.3	UWE Bristol	Oil B 589nm	76.60(99)	75.74	1.51626	1.51626	2/19/2001	05:02
8/1.4	UWE Bristol	Oil B 589nm	76.60(99)	75.74	1.51626	1.51626	2/19/2001	05:02
9/1.1	UWE Bristol	Oil B 589nm	76.37(40)	75.525	1.51634	1.51634	2/19/2001	05:10
9/1.2	UWE Bristol	Oil B 589nm	76.55(99)	75.725	1.51627	1.51627	2/19/2001	05:10
9/1.3	UWE Bristol	Oil B 589nm	76.63(99)	75.805	1.51624	1.51624	2/19/2001	05:10
9/1.4	UWE Bristol	Oil B 589nm	76.62(99)	75.8	1.51624	1.51624	2/19/2001	05:10
10/1.1	UWE Bristol	Oil B 589nm	76.62(99)	75.9	1.5162	1.51620	2/19/2001	05:17
10/1.2	UWE Bristol	Oil B 589nm	76.61(85)	75.9	1.5162	1.51620	2/19/2001	05:17
10/1.3	UWE Bristol	Oil B 589nm	76.57(99)	75.84	1.51622	1.51622	2/19/2001	05:17
10/1.4	UWE Bristol	Oil B 589nm	76.51(88)	75.79	1.51624	1.51624	2/19/2001	05:17
11/1.1	UWE Bristol	Oil B 589nm	76.71(99)	75.935	1.51619	1.51619	2/19/2001	05:23
11/1.2	UWE Bristol	Oil B 589nm	76.90(58)	76.12	1.51612	1.51612	2/19/2001	05:23
11/1.3	UWE Bristol	Oil B 589nm	76.66(99)	75.9	1.5162	1.51620	2/19/2001	05:23
11/1.4	UWE Bristol	Oil B 589nm	76.58(99)	75.82	1.51623	1.51623	2/19/2001	05:23
12/1.1	UWE Bristol	Oil B 589nm	76.63(99)	75.91	1.5162	1.51620	2/19/2001	05:30
12/1.2	UWE Bristol	Oil B 589nm	76.60(99)	75.895	1.51621	1.51621	2/19/2001	05:30
12/1.3	UWE Bristol	Oil B 589nm	76.58(99)	75.87	1.51621	1.51621	2/19/2001	05:30
12/1.4	UWE Bristol	Oil B 589nm	76.35(30)	75.65	1.51629	1.51629	2/19/2001	05:30
Mean of 48 Samples: 75.69				Range: 74.43 - 76.12		SD: 0.252		
				1.51628		Range: 1.51612 - 1.51675		
						SD: 0.0000934		

Control Sample AuFOR05: car, Float Toughened, Colourless

1/1.1	UWE Bristol	Oil B 589nm	76.94(51)	76.06	1.51614	1.51614	2/19/2001	05:43
1/1.2	UWE Bristol	Oil B 589nm	76.76(34)	75.87	1.51621	1.51621	2/19/2001	05:43
1/1.3	UWE Bristol	Oil B 589nm	76.71(30)	75.82	1.51623	1.51623	2/19/2001	05:43
1/1.4	UWE Bristol	Oil B 589nm	77.01(22)	76.065	1.51614	1.51614	2/19/2001	05:43
2/1.1	UWE Bristol	Oil B 589nm	76.98(55)	76.125	1.51612	1.51612	2/19/2001	05:51
2/1.2	UWE Bristol	Oil B 589nm	77.16(17)	76.21	1.51609	1.51609	2/19/2001	05:51
2/1.3	UWE Bristol	Oil B 589nm	76.93(34)	75.955	1.51618	1.51618	2/19/2001	05:51
2/1.4	UWE Bristol	Oil B 589nm	76.93(35)	76.065	1.51614	1.51614	2/19/2001	05:51
3/1.1	UWE Bristol	Oil B 589nm	77.13(33)	76.23	1.51608	1.51608	2/19/2001	06:00
3/1.2	UWE Bristol	Oil B 589nm	77.19(52)	76.285	1.51606	1.51606	2/19/2001	06:00
3/1.3	UWE Bristol	Oil B 589nm	77.11(49)	76.17	1.5161	1.51610	2/19/2001	06:00
3/1.4	UWE Bristol	Oil B 589nm	76.96(49)	76.045	1.51615	1.51615	2/19/2001	06:00
4/1.1	UWE Bristol	Oil B 589nm	76.88(99)	76	1.51617	1.51617	2/19/2001	06:08
4/1.2	UWE Bristol	Oil B 589nm	77.00(82)	76	1.51617	1.51617	2/19/2001	06:08
4/1.3	UWE Bristol	Oil B 589nm	76.78(29)	75.74	1.51626	1.51626	2/19/2001	06:08
4/1.4	UWE Bristol	Oil B 589nm	76.93(60)	75.955	1.51618	1.51618	2/19/2001	06:08
5/1.1	UWE Bristol	Oil B 589nm	77.10(29)	76.185	1.5161	1.51610	2/19/2001	06:14
5/1.2	UWE Bristol	Oil B 589nm	77.22(22)	76.265	1.51607	1.51607	2/19/2001	06:14
5/1.3	UWE Bristol	Oil B 589nm	77.11(91)	76.2	1.51609	1.51609	2/19/2001	06:14
5/1.4	UWE Bristol	Oil B 589nm	76.93(51)	75.97	1.51618	1.51618	2/19/2001	06:14
6/1.1	UWE Bristol	Oil B 589nm	77.03(82)	76.085	1.51614	1.51614	2/19/2001	06:20
6/1.2	UWE Bristol	Oil B 589nm	77.01(99)	76.06	1.51614	1.51614	2/19/2001	06:20
6/1.3	UWE Bristol	Oil B 589nm	76.98(99)	76.045	1.51615	1.51615	2/19/2001	06:20
6/1.4	UWE Bristol	Oil B 589nm	76.93(99)	76.005	1.51617	1.51617	2/19/2001	06:20
7/1.1	UWE Bristol	Oil B 589nm	76.76(41)	75.96	1.51618	1.51618	2/22/2001	00:23
7/1.2	UWE Bristol	Oil B 589nm	77.06(74)	76.265	1.51607	1.51607	2/22/2001	00:23
7/1.3	UWE Bristol	Oil B 589nm	77.07(76)	76.26	1.51607	1.51607	2/22/2001	00:23
7/1.4	UWE Bristol	Oil B 589nm	77.23(21)	76.35	1.51604	1.51604	2/22/2001	00:23

8/1.1	UWE Bristol	Oil B 589nm	76.42(70)	75.575	1.51632	1.51632	2/22/2001	00:30
8/1.2	UWE Bristol	Oil B 589nm	76.42(67)	75.57	1.51632	1.51632	2/22/2001	00:30
8/1.3	UWE Bristol	Oil B 589nm	76.37(85)	75.51	1.51635	1.51635	2/22/2001	00:30
8/1.4	UWE Bristol	Oil B 589nm	76.30(99)	75.46	1.51636	1.51636	2/22/2001	00:30
9/1.1	UWE Bristol	Oil B 589nm	76.28(95)	75.48	1.51636	1.51636	2/22/2001	00:40
9/1.2	UWE Bristol	Oil B 589nm	76.27(77)	75.46	1.51636	1.51636	2/22/2001	00:40
9/1.3	UWE Bristol	Oil B 589nm	76.23(99)	75.425	1.51638	1.51638	2/22/2001	00:40
9/1.4	UWE Bristol	Oil B 589nm	76.30(69)	75.515	1.51635	1.51635	2/22/2001	00:40
10/1.1	UWE Bristol	Oil B 589nm	77.02(20)	76.05	1.51615	1.51615	2/22/2001	00:52
10/1.2	UWE Bristol	Oil B 589nm	76.98(18)	76.015	1.51616	1.51616	2/22/2001	00:52
10/1.3	UWE Bristol	Oil B 589nm	76.98(15)	76.075	1.51614	1.51614	2/22/2001	00:52
10/1.4	UWE Bristol	Oil B 589nm	76.94(22)	76.105	1.51613	1.51613	2/22/2001	00:52
11/1.1	UWE Bristol	Oil B 589nm	76.89(31)	75.925	1.5162	1.51620	2/22/2001	01:03
11/1.2	UWE Bristol	Oil B 589nm	76.86(34)	75.91	1.5162	1.51620	2/22/2001	01:03
11/1.3	UWE Bristol	Oil B 589nm	76.98(86)	76.05	1.51615	1.51615	2/22/2001	01:03
11/1.4	UWE Bristol	Oil B 589nm	76.91(58)	75.93	1.51619	1.51619	2/22/2001	01:03
12/1.1	UWE Bristol	Oil B 589nm	77.26(73)	76.33	1.51605	1.51605	2/22/2001	01:13
12/1.2	UWE Bristol	Oil B 589nm	77.11(46)	76.145	1.51611	1.51611	2/22/2001	01:13
12/1.3	UWE Bristol	Oil B 589nm	76.94(99)	76.025	1.51616	1.51616	2/22/2001	01:13
12/1.4	UWE Bristol	Oil B 589nm	76.91(29)	76.01	1.51616	1.51616	2/22/2001	01:13
Mean of 48 Samples: 75.98 Range: 75.43 - 76.35 SD: 0.248								
1.51618 Range: 1.51604 - 1.51638 SD: 0.0000908								

Control Sample AuNIS01: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	67.64(99)	66.82	1.51953	1.51953	1/27/2009	14:31
1/1.2	UWE Bristol	Oil B 589nm	67.71(99)	66.89	1.5195	1.51950	1/27/2009	14:31
1/1.3	UWE Bristol	Oil B 589nm	67.53(99)	66.725	1.51957	1.51957	1/27/2009	14:31
1/1.4	UWE Bristol	Oil B 589nm	67.57(99)	66.75	1.51956	1.51956	1/27/2009	14:31
2/1.1	UWE Bristol	Oil B 589nm	67.94(99)	67.13	1.51942	1.51942	1/27/2009	14:39
2/1.2	UWE Bristol	Oil B 589nm	67.98(83)	67.17	1.5194	1.51940	1/27/2009	14:39

2/1.3	UWE Bristol	Oil B 589nm	67.53(99)	66.71	1.51957	1.51957	1/27/2009	14:39
2/1.4	UWE Bristol	Oil B 589nm	67.63(99)	66.825	1.51953	1.51953	1/27/2009	14:39
3/1.1	UWE Bristol	Oil B 589nm	67.53(99)	66.715	1.51957	1.51957	1/27/2009	14:51
3/1.2	UWE Bristol	Oil B 589nm	67.44(99)	66.63	1.5196	1.51960	1/27/2009	14:51
3/1.3	UWE Bristol	Oil B 589nm	67.23(99)	66.41	1.51968	1.51968	1/27/2009	14:51
3/1.4	UWE Bristol	Oil B 589nm	67.41(97)	66.605	1.51961	1.51961	1/27/2009	14:51
4/1.1	UWE Bristol	Oil B 589nm	67.46(99)	66.47	1.51966	1.51966	2/18/2009	15:27
4/1.2	UWE Bristol	Oil B 589nm	67.40(99)	66.41	1.51968	1.51968	2/18/2009	15:27
4/1.3	UWE Bristol	Oil B 589nm	67.48(99)	66.5	1.51965	1.51965	2/18/2009	15:27
4/1.4	UWE Bristol	Oil B 589nm	67.42(99)	66.425	1.51968	1.51968	2/18/2009	15:27
5/1.1	UWE Bristol	Oil B 589nm	67.43(99)	66.545	1.51963	1.51963	2/18/2009	15:34
5/1.2	UWE Bristol	Oil B 589nm	67.36(99)	66.43	1.51967	1.51967	2/18/2009	15:34
5/1.3	UWE Bristol	Oil B 589nm	67.32(99)	66.38	1.51969	1.51969	2/18/2009	15:34
5/1.4	UWE Bristol	Oil B 589nm	67.36(99)	66.405	1.51968	1.51968	2/18/2009	15:34
6/1.1	UWE Bristol	Oil B 589nm	67.47(99)	66.52	1.51964	1.51964	2/18/2009	15:40
6/1.2	UWE Bristol	Oil B 589nm	67.48(99)	66.525	1.51964	1.51964	2/18/2009	15:40
6/1.3	UWE Bristol	Oil B 589nm	67.44(99)	66.485	1.51965	1.51965	2/18/2009	15:40
6/1.4	UWE Bristol	Oil B 589nm	67.53(99)	66.575	1.51962	1.51962	2/18/2009	15:40
7/1.1	UWE Bristol	Oil B 589nm	67.40(99)	66.48	1.51965	1.51965	2/20/2009	11:03
7/1.2	UWE Bristol	Oil B 589nm	67.25(99)	66.375	1.51969	1.51969	2/20/2009	11:03
7/1.3	UWE Bristol	Oil B 589nm	67.31(99)	66.435	1.51967	1.51967	2/20/2009	11:03
7/1.4	UWE Bristol	Oil B 589nm	67.50(99)	66.605	1.51961	1.51961	2/20/2009	11:03
8/1.1	UWE Bristol	Oil B 589nm	67.48(99)	66.64	1.5196	1.51960	2/20/2009	11:10
8/1.2	UWE Bristol	Oil B 589nm	67.48(99)	66.645	1.5196	1.51960	2/20/2009	11:10
8/1.3	UWE Bristol	Oil B 589nm	67.31(95)	66.49	1.51965	1.51965	2/20/2009	11:10
8/1.4	UWE Bristol	Oil B 589nm	67.33(60)	66.505	1.51965	1.51965	2/20/2009	11:10
9/1.1	UWE Bristol	Oil B 589nm	67.48(99)	66.615	1.51961	1.51961	2/20/2009	11:27
9/1.2	UWE Bristol	Oil B 589nm	67.46(99)	66.595	1.51961	1.51961	2/20/2009	11:27
9/1.3	UWE Bristol	Oil B 589nm	67.51(99)	66.65	1.51959	1.51959	2/20/2009	11:27
9/1.4	UWE Bristol	Oil B 589nm	67.51(99)	66.655	1.51959	1.51959	2/20/2009	11:27

10/1.1	UWE Bristol	Oil B 589nm	67.83(99)	66.905	1.5195	1.51950	2/20/2009	11:35
10/1.2	UWE Bristol	Oil B 589nm	67.82(99)	66.885	1.51951	1.51951	2/20/2009	11:35
10/1.3	UWE Bristol	Oil B 589nm	67.88(99)	66.95	1.51948	1.51948	2/20/2009	11:35
10/1.4	UWE Bristol	Oil B 589nm	67.72(99)	66.8	1.51954	1.51954	2/20/2009	11:35
11/1.1	UWE Bristol	Oil B 589nm	67.96(67)	66.995	1.51947	1.51947	2/20/2009	11:53
11/1.2	UWE Bristol	Oil B 589nm	68.07(99)	67.125	1.51942	1.51942	2/20/2009	11:53
11/1.3	UWE Bristol	Oil B 589nm	68.05(99)	67.11	1.51942	1.51942	2/20/2009	11:53
11/1.4	UWE Bristol	Oil B 589nm	68.06(99)	67.1	1.51943	1.51943	2/20/2009	11:53
12/1.1	UWE Bristol	Oil B 589nm	67.73(93)	66.8	1.51954	1.51954	2/20/2009	12:02
12/1.2	UWE Bristol	Oil B 589nm	67.40(63)	66.46	1.51966	1.51966	2/20/2009	12:02
12/1.3	UWE Bristol	Oil B 589nm	67.79(73)	66.865	1.51951	1.51951	2/20/2009	12:02
12/1.4	UWE Bristol	Oil B 589nm	67.75(73)	66.82	1.51953	1.51953	2/20/2009	12:02
Mean of 48 Samples: 66.68 Range: 66.38 - 67.17 SD: 0.224								
1.51958 Range: 1.51940 - 1.51969 SD: 0.0000818								

Control Sample AuROV01: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	68.08(27)	67.105	1.51943	1.51943	3/5/2001	03:37
1/1.2	UWE Bristol	Oil B 589nm	68.05(49)	67.135	1.51942	1.51942	3/5/2001	03:37
1/1.3	UWE Bristol	Oil B 589nm	68.07(59)	67.19	1.51939	1.51939	3/5/2001	03:37
1/1.4	UWE Bristol	Oil B 589nm	68.04(42)	67.13	1.51942	1.51942	3/5/2001	03:37
2/1.1	UWE Bristol	Oil B 589nm	68.12(99)	67.23	1.51938	1.51938	3/5/2001	03:45
2/1.2	UWE Bristol	Oil B 589nm	68.46(99)	67.56	1.51926	1.51926	3/5/2001	03:45
2/1.3	UWE Bristol	Oil B 589nm	67.95(99)	67.01	1.51946	1.51946	3/5/2001	03:45
2/1.4	UWE Bristol	Oil B 589nm	66.40(99)	65.495	1.52002	1.52002	3/5/2001	03:45
3/1.1	UWE Bristol	Oil B 589nm	67.22(60)	66.38	1.51969	1.51969	3/5/2001	03:53
3/1.2	UWE Bristol	Oil B 589nm	67.71(99)	66.84	1.51952	1.51952	3/5/2001	03:53
3/1.3	UWE Bristol	Oil B 589nm	67.83(99)	66.93	1.51949	1.51949	3/5/2001	03:53
3/1.4	UWE Bristol	Oil B 589nm	67.56(99)	66.675	1.51958	1.51958	3/5/2001	03:53
4/1.1	UWE Bristol	Oil B 589nm	67.98(99)	67.065	1.51944	1.51944	3/5/2001	04:05
4/1.2	UWE Bristol	Oil B 589nm	67.92(99)	66.995	1.51947	1.51947	3/5/2001	04:05

4/1.3	UWE Bristol	Oil B 589nm	67.98(37)	67.02	1.51946	1.51946	3/5/2001	04:05
4/1.4	UWE Bristol	Oil B 589nm	67.77(64)	66.92	1.51949	1.51949	3/5/2001	04:05
5/1.1	UWE Bristol	Oil B 589nm	67.91(76)	67	1.51946	1.51946	3/5/2001	04:13
5/1.2	UWE Bristol	Oil B 589nm	67.92(85)	67.005	1.51946	1.51946	3/5/2001	04:13
5/1.3	UWE Bristol	Oil B 589nm	67.94(60)	67.015	1.51946	1.51946	3/5/2001	04:13
5/1.4	UWE Bristol	Oil B 589nm	67.75(64)	66.835	1.51953	1.51953	3/5/2001	04:13
6/1.1	UWE Bristol	Oil B 589nm	67.84(25)	66.92	1.51949	1.51949	3/5/2001	04:21
6/1.2	UWE Bristol	Oil B 589nm	68.00(48)	67.115	1.51942	1.51942	3/5/2001	04:21
6/1.3	UWE Bristol	Oil B 589nm	67.90(63)	66.99	1.51947	1.51947	3/5/2001	04:21
6/1.4	UWE Bristol	Oil B 589nm	67.95(29)	67.02	1.51946	1.51946	3/5/2001	04:21
7/1.1	UWE Bristol	Oil B 589nm	67.92(59)	66.98	1.51947	1.51947	3/5/2001	04:30
7/1.2	UWE Bristol	Oil B 589nm	67.93(53)	66.955	1.51948	1.51948	3/5/2001	04:30
7/1.3	UWE Bristol	Oil B 589nm	67.71(33)	66.75	1.51956	1.51956	3/5/2001	04:30
7/1.4	UWE Bristol	Oil B 589nm	67.79(26)	66.88	1.51951	1.51951	3/5/2001	04:30
8/1.1	UWE Bristol	Oil B 589nm	67.90(99)	66.95	1.51948	1.51948	3/5/2001	04:38
8/1.2	UWE Bristol	Oil B 589nm	67.89(85)	66.92	1.51949	1.51949	3/5/2001	04:38
8/1.3	UWE Bristol	Oil B 589nm	67.90(75)	66.925	1.51949	1.51949	3/5/2001	04:38
8/1.4	UWE Bristol	Oil B 589nm	68.08(63)	67.165	1.5194	1.51940	3/5/2001	04:38
9/1.1	UWE Bristol	Oil B 589nm	67.88(18)	66.89	1.5195	1.51950	3/5/2001	04:46
9/1.2	UWE Bristol	Oil B 589nm	68.04(16)	67.08	1.51943	1.51943	3/5/2001	04:46
9/1.3	UWE Bristol	Oil B 589nm	67.90(25)	67.01	1.51946	1.51946	3/5/2001	04:46
9/1.4	UWE Bristol	Oil B 589nm	67.81(39)	66.895	1.5195	1.51950	3/5/2001	04:46
10/1.1	UWE Bristol	Oil B 589nm	67.79(46)	66.95	1.51948	1.51948	3/5/2001	04:54
10/1.2	UWE Bristol	Oil B 589nm	67.79(47)	66.96	1.51948	1.51948	3/5/2001	04:54
10/1.3	UWE Bristol	Oil B 589nm	67.87(63)	67.035	1.51945	1.51945	3/5/2001	04:54
10/1.4	UWE Bristol	Oil B 589nm	67.93(77)	67.08	1.51943	1.51943	3/5/2001	04:54
11/1.1	UWE Bristol	Oil B 589nm	67.81(17)	66.98	1.51947	1.51947	3/5/2001	05:06
11/1.2	UWE Bristol	Oil B 589nm	67.89(16)	67.02	1.51946	1.51946	3/5/2001	05:06
11/1.3	UWE Bristol	Oil B 589nm	67.98(30)	67.14	1.51941	1.51941	3/5/2001	05:06
11/1.4	UWE Bristol	Oil B 589nm	67.89(16)	67.04	1.51945	1.51945	3/5/2001	05:06

12/1.1	UWE Bristol	Oil B 589nm	67.79(44)	66.925	1.51949	1.51949	3/5/2001	05:15
12/1.2	UWE Bristol	Oil B 589nm	67.79(34)	66.895	1.5195	1.51950	3/5/2001	05:15
12/1.3	UWE Bristol	Oil B 589nm	67.96(23)	67.08	1.51943	1.51943	3/5/2001	05:15
12/1.4	UWE Bristol	Oil B 589nm	67.80(69)	66.935	1.51949	1.51949	3/5/2001	05:15
Mean of 48 Samples: 66.96				Range: 65.50 - 67.56		SD: 0.267		
				1.51948		Range: 1.51926 - 1.52002		SD: 0.0000984

Control Sample AuROV02: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	65.66(10)	64.785	1.52028	1.52028	3/20/2001	00:33
1/1.2	UWE Bristol	Oil B 589nm	65.84(21)	64.98	1.5202	1.52020	3/20/2001	00:33
1/1.3	UWE Bristol	Oil B 589nm	65.44(32)	64.67	1.52032	1.52032	3/20/2001	00:33
1/1.4	UWE Bristol	Oil B 589nm	65.81(32)	65.13	1.52015	1.52015	3/20/2001	00:33
2/1.1	UWE Bristol	Oil B 589nm	66.31(56)	65.51	1.52001	1.52001	3/20/2001	00:42
2/1.2	UWE Bristol	Oil B 589nm	66.14(99)	65.335	1.52008	1.52008	3/20/2001	00:42
2/1.3	UWE Bristol	Oil B 589nm	66.09(99)	65.285	1.52009	1.52009	3/20/2001	00:42
2/1.4	UWE Bristol	Oil B 589nm	66.00(99)	65.19	1.52013	1.52013	3/20/2001	00:42
3/1.1	UWE Bristol	Oil B 589nm	65.97(99)	65.225	1.52012	1.52012	3/20/2001	00:56
3/1.2	UWE Bristol	Oil B 589nm	66.03(99)	65.305	1.52009	1.52009	3/20/2001	00:56
3/1.3	UWE Bristol	Oil B 589nm	66.39(99)	65.685	1.51995	1.51995	3/20/2001	00:56
3/1.4	UWE Bristol	Oil B 589nm	66.25(78)	65.53	1.52	1.52000	3/20/2001	00:56
4/1.1	UWE Bristol	Oil B 589nm	65.94(15)	64.935	1.52022	1.52022	3/20/2001	01:06
4/1.2	UWE Bristol	Oil B 589nm	66.34(10)	65.28	1.52009	1.52009	3/20/2001	01:06
4/1.3	UWE Bristol	Oil B 589nm	66.13(27)	65.135	1.52015	1.52015	3/20/2001	01:06
4/1.4	UWE Bristol	Oil B 589nm	66.13(36)	65.11	1.52016	1.52016	3/20/2001	01:06
5/1.1	UWE Bristol	Oil B 589nm	66.25(48)	65.27	1.5201	1.52010	3/20/2001	01:15
5/1.2	UWE Bristol	Oil B 589nm	66.33(99)	65.31	1.52008	1.52008	3/20/2001	01:15
5/1.3	UWE Bristol	Oil B 589nm	66.44(44)	65.405	1.52005	1.52005	3/20/2001	01:15
5/1.4	UWE Bristol	Oil B 589nm	66.36(70)	65.34	1.52007	1.52007	3/20/2001	01:15
6/1.1	UWE Bristol	Oil B 589nm	66.28(25)	65.25	1.5201	1.52010	3/20/2001	01:24
6/1.2	UWE Bristol	Oil B 589nm	65.83(31)	64.95	1.52021	1.52021	3/20/2001	01:24

6/1.3	UWE Bristol	Oil B 589nm	66.40(26)	65.42	1.52004	1.52004	3/20/2001	01:24
6/1.4	UWE Bristol	Oil B 589nm	66.31(17)	65.345	1.52007	1.52007	3/20/2001	01:24
7/1.1	UWE Bristol	Oil B 589nm	66.53(19)	65.605	1.51998	1.51998	3/20/2001	01:35
7/1.2	UWE Bristol	Oil B 589nm	66.00(39)	65.1	1.52016	1.52016	3/20/2001	01:35
7/1.3	UWE Bristol	Oil B 589nm	66.33(38)	65.455	1.52003	1.52003	3/20/2001	01:35
7/1.4	UWE Bristol	Oil B 589nm	66.20(61)	65.38	1.52006	1.52006	3/20/2001	01:35
8/1.1	UWE Bristol	Oil B 589nm	66.20(16)	65.445	1.52004	1.52004	3/20/2001	01:43
8/1.2	UWE Bristol	Oil B 589nm	66.40(18)	65.555	1.51999	1.51999	3/20/2001	01:43
8/1.3	UWE Bristol	Oil B 589nm	66.20(54)	65.465	1.52003	1.52003	3/20/2001	01:43
8/1.4	UWE Bristol	Oil B 589nm	66.13(44)	65.28	1.52009	1.52009	3/20/2001	01:43
9/1.1	UWE Bristol	Oil B 589nm	66.33(47)	65.525	1.52001	1.52001	3/20/2001	01:51
9/1.2	UWE Bristol	Oil B 589nm	66.25(49)	65.45	1.52003	1.52003	3/20/2001	01:51
9/1.3	UWE Bristol	Oil B 589nm	66.21(24)	65.44	1.52004	1.52004	3/20/2001	01:51
9/1.4	UWE Bristol	Oil B 589nm	66.27(30)	65.45	1.52003	1.52003	3/20/2001	01:51
10/1.1	UWE Bristol	Oil B 589nm	66.09(45)	65.005	1.5202	1.52020	3/20/2001	01:59
10/1.2	UWE Bristol	Oil B 589nm	66.04(99)	65.015	1.52019	1.52019	3/20/2001	01:59
10/1.3	UWE Bristol	Oil B 589nm	66.06(99)	65.01	1.52019	1.52019	3/20/2001	01:59
10/1.4	UWE Bristol	Oil B 589nm	65.98(37)	64.93	1.52022	1.52022	3/20/2001	01:59
11/1.1	UWE Bristol	Oil B 589nm	66.26(36)	65.215	1.52012	1.52012	3/20/2001	02:07
11/1.2	UWE Bristol	Oil B 589nm	66.18(73)	65.205	1.52012	1.52012	3/20/2001	02:07
11/1.3	UWE Bristol	Oil B 589nm	66.32(31)	65.24	1.52011	1.52011	3/20/2001	02:07
11/1.4	UWE Bristol	Oil B 589nm	66.17(99)	65.105	1.52016	1.52016	3/20/2001	02:07
12/1.1	UWE Bristol	Oil B 589nm	66.11(99)	65.1	1.52016	1.52016	3/20/2001	02:17
12/1.2	UWE Bristol	Oil B 589nm	66.15(99)	65.14	1.52015	1.52015	3/20/2001	02:17
12/1.3	UWE Bristol	Oil B 589nm	65.58(99)	64.595	1.52035	1.52035	3/20/2001	02:17
12/1.4	UWE Bristol	Oil B 589nm	65.72(99)	64.735	1.5203	1.52030	3/20/2001	02:17

Mean of 48 Samples: 65.23 Range: 64.60 - 65.68 SD: 0.244
1.52011 Range: 1.51995 - 1.52035 SD: 0.0000897

Control Sample AuVW01: car, Float Laminated

1/1.1	UWE Bristol	Oil B 589nm	61.40(73)	60.36	1.5219	1.52190	2/20/2009	14:36
1/1.2	UWE Bristol	Oil B 589nm	61.36(68)	60.305	1.52192	1.52192	2/20/2009	14:36
1/1.3	UWE Bristol	Oil B 589nm	61.41(69)	60.33	1.52191	1.52191	2/20/2009	14:36
1/1.4	UWE Bristol	Oil B 589nm	61.24(65)	60.19	1.52196	1.52196	2/20/2009	14:36
2/1.1	UWE Bristol	Oil B 589nm	61.48(99)	60.425	1.52187	1.52187	2/20/2009	14:52
2/1.2	UWE Bristol	Oil B 589nm	61.43(99)	60.39	1.52189	1.52189	2/20/2009	14:52
2/1.3	UWE Bristol	Oil B 589nm	61.40(99)	60.345	1.5219	1.52190	2/20/2009	14:52
2/1.4	UWE Bristol	Oil B 589nm	61.29(99)	60.23	1.52194	1.52194	2/20/2009	14:52
3/1.1	UWE Bristol	Oil B 589nm	61.22(75)	60.095	1.522	1.52200	2/20/2009	15:13
3/1.2	UWE Bristol	Oil B 589nm	61.20(93)	60.07	1.522	1.52200	2/20/2009	15:13
3/1.3	UWE Bristol	Oil B 589nm	61.30(35)	60.165	1.52197	1.52197	2/20/2009	15:13
3/1.4	UWE Bristol	Oil B 589nm	61.29(30)	60.165	1.52197	1.52197	2/20/2009	15:13
4/1.1	UWE Bristol	Oil B 589nm	61.90(56)	60.87	1.52171	1.52171	2/20/2009	15:21
4/1.2	UWE Bristol	Oil B 589nm	61.90(45)	60.905	1.5217	1.52170	2/20/2009	15:21
4/1.3	UWE Bristol	Oil B 589nm	61.85(64)	60.82	1.52173	1.52173	2/20/2009	15:21
4/1.4	UWE Bristol	Oil B 589nm	61.66(82)	60.63	1.5218	1.52180	2/20/2009	15:21
5/1.1	UWE Bristol	Oil B 589nm	61.56(81)	60.48	1.52185	1.52185	2/20/2009	15:28
5/1.2	UWE Bristol	Oil B 589nm	62.03(57)	60.945	1.52168	1.52168	2/20/2009	15:28
5/1.3	UWE Bristol	Oil B 589nm	61.84(60)	60.83	1.52172	1.52172	2/20/2009	15:28
5/1.4	UWE Bristol	Oil B 589nm	61.81(43)	60.76	1.52175	1.52175	2/20/2009	15:28
6/1.1	UWE Bristol	Oil B 589nm	61.33(37)	60.3	1.52192	1.52192	2/20/2009	15:35
6/1.2	UWE Bristol	Oil B 589nm	61.55(43)	60.505	1.52185	1.52185	2/20/2009	15:35
6/1.3	UWE Bristol	Oil B 589nm	61.39(41)	60.37	1.52189	1.52189	2/20/2009	15:35
6/1.4	UWE Bristol	Oil B 589nm	61.59(30)	60.535	1.52183	1.52183	2/20/2009	15:35
7/1.1	UWE Bristol	Oil B 589nm	61.18(56)	60.285	1.52193	1.52193	2/20/2009	15:44
7/1.2	UWE Bristol	Oil B 589nm	61.52(99)	60.59	1.52181	1.52181	2/20/2009	15:44
7/1.3	UWE Bristol	Oil B 589nm	61.42(64)	60.465	1.52186	1.52186	2/20/2009	15:44
7/1.4	UWE Bristol	Oil B 589nm	61.53(77)	60.58	1.52182	1.52182	2/20/2009	15:44
8/1.1	UWE Bristol	Oil B 589nm	61.23(69)	60.33	1.52191	1.52191	2/20/2009	15:52

8/1.2	UWE Bristol	Oil B 589nm	61.46(50)	60.555	1.52183	1.52183	2/20/2009	15:52
8/1.3	UWE Bristol	Oil B 589nm	61.48(68)	60.605	1.52181	1.52181	2/20/2009	15:52
8/1.4	UWE Bristol	Oil B 589nm	61.48(51)	60.585	1.52182	1.52182	2/20/2009	15:52
9/1.1	UWE Bristol	Oil B 589nm	61.34(99)	60.38	1.52189	1.52189	2/20/2009	16:09
9/1.2	UWE Bristol	Oil B 589nm	61.36(42)	60.395	1.52189	1.52189	2/20/2009	16:09
9/1.3	UWE Bristol	Oil B 589nm	61.52(80)	60.565	1.52182	1.52182	2/20/2009	16:09
9/1.4	UWE Bristol	Oil B 589nm	61.50(94)	60.54	1.52183	1.52183	2/20/2009	16:09
10/1.1	UWE Bristol	Oil B 589nm	60.85(20)	59.995	1.52203	1.52203	2/20/2009	16:17
10/1.2	UWE Bristol	Oil B 589nm	61.31(21)	60.445	1.52187	1.52187	2/20/2009	16:17
10/1.3	UWE Bristol	Oil B 589nm	61.11(17)	60.205	1.52195	1.52195	2/20/2009	16:17
10/1.4	UWE Bristol	Oil B 589nm	61.28(21)	60.415	1.52188	1.52188	2/20/2009	16:17
11/1.1	UWE Bristol	Oil B 589nm	61.37(9)	60.345	1.5219	1.52190	2/20/2009	16:38
11/1.2	UWE Bristol	Oil B 589nm	61.34(17)	60.325	1.52191	1.52191	2/20/2009	16:38
11/1.3	UWE Bristol	Oil B 589nm	61.26(16)	60.245	1.52194	1.52194	2/20/2009	16:38
11/1.4	UWE Bristol	Oil B 589nm	61.42(15)	60.44	1.52187	1.52187	2/20/2009	16:38

Mean of 44 Samples: 60.44 Range: 59.99 - 60.94 SD: 0.223
1.52187 Range: 1.52168 - 1.52203 SD: 0.0000817

Control Sample AuVW02: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	64.28(99)	63.45	1.52076	1.52076	1/27/2009	15:50
1/1.2	UWE Bristol	Oil B 589nm	64.28(99)	63.46	1.52076	1.52076	1/27/2009	15:50
1/1.3	UWE Bristol	Oil B 589nm	64.31(99)	63.49	1.52075	1.52075	1/27/2009	15:50
1/1.4	UWE Bristol	Oil B 589nm	64.36(99)	63.535	1.52073	1.52073	1/27/2009	15:50
2/1.1	UWE Bristol	Oil B 589nm	64.50(99)	63.69	1.52068	1.52068	1/27/2009	16:04
2/1.2	UWE Bristol	Oil B 589nm	64.66(99)	63.865	1.52061	1.52061	1/27/2009	16:04
2/1.3	UWE Bristol	Oil B 589nm	64.51(99)	63.695	1.52068	1.52068	1/27/2009	16:04
2/1.4	UWE Bristol	Oil B 589nm	64.71(99)	63.91	1.5206	1.52060	1/27/2009	16:04
3/1.1	UWE Bristol	Oil B 589nm	64.93(99)	64.125	1.52052	1.52052	1/27/2009	16:13
3/1.2	UWE Bristol	Oil B 589nm	64.97(99)	64.175	1.5205	1.52050	1/27/2009	16:13
4/1.1	UWE Bristol	Oil B 589nm	64.03(26)	63.275	1.52083	1.52083	3/5/2001	00:32

4/1.2	UWE Bristol	Oil B 589nm	64.19(16)	63.47	1.52076	1.52076	3/5/2001	00:32
4/1.3	UWE Bristol	Oil B 589nm	63.84(19)	63.16	1.52087	1.52087	3/5/2001	00:32
4/1.4	UWE Bristol	Oil B 589nm	64.38(31)	63.69	1.52068	1.52068	3/5/2001	00:32
5/1.1	UWE Bristol	Oil B 589nm	64.72(37)	63.96	1.52058	1.52058	3/5/2001	00:39
5/1.2	UWE Bristol	Oil B 589nm	64.75(48)	64.02	1.52056	1.52056	3/5/2001	00:39
5/1.3	UWE Bristol	Oil B 589nm	64.91(44)	64.16	1.5205	1.52050	3/5/2001	00:39
5/1.4	UWE Bristol	Oil B 589nm	64.59(31)	63.835	1.52062	1.52062	3/5/2001	00:39
6/1.1	UWE Bristol	Oil B 589nm	64.70(36)	63.935	1.52059	1.52059	3/5/2001	00:47
6/1.2	UWE Bristol	Oil B 589nm	64.63(47)	63.85	1.52062	1.52062	3/5/2001	00:47
6/1.3	UWE Bristol	Oil B 589nm	64.53(17)	63.71	1.52067	1.52067	3/5/2001	00:47
6/1.4	UWE Bristol	Oil B 589nm	64.62(8)	63.755	1.52065	1.52065	3/5/2001	00:47
7/1.1	UWE Bristol	Oil B 589nm	64.65(83)	63.86	1.52061	1.52061	3/5/2001	00:56
7/1.2	UWE Bristol	Oil B 589nm	64.38(99)	63.57	1.52072	1.52072	3/5/2001	00:56
7/1.3	UWE Bristol	Oil B 589nm	64.14(69)	63.32	1.52081	1.52081	3/5/2001	00:56
7/1.4	UWE Bristol	Oil B 589nm	64.07(80)	63.255	1.52084	1.52084	3/5/2001	00:56
8/1.1	UWE Bristol	Oil B 589nm	64.38(39)	63.52	1.52074	1.52074	3/5/2001	01:05
8/1.2	UWE Bristol	Oil B 589nm	64.32(99)	63.51	1.52074	1.52074	3/5/2001	01:05
8/1.3	UWE Bristol	Oil B 589nm	64.03(24)	63.265	1.52083	1.52083	3/5/2001	01:05
8/1.4	UWE Bristol	Oil B 589nm	64.41(39)	63.595	1.52071	1.52071	3/5/2001	01:05
9/1.1	UWE Bristol	Oil B 589nm	64.25(99)	63.41	1.52078	1.52078	3/5/2001	01:12
9/1.2	UWE Bristol	Oil B 589nm	64.18(99)	63.34	1.5208	1.52080	3/5/2001	01:12
9/1.3	UWE Bristol	Oil B 589nm	64.45(75)	63.6	1.52071	1.52071	3/5/2001	01:12
9/1.4	UWE Bristol	Oil B 589nm	64.19(89)	63.39	1.52079	1.52079	3/5/2001	01:12
10/1.1	UWE Bristol	Oil B 589nm	64.44(50)	63.65	1.52069	1.52069	3/5/2001	01:22
10/1.2	UWE Bristol	Oil B 589nm	64.34(88)	63.555	1.52073	1.52073	3/5/2001	01:22
10/1.3	UWE Bristol	Oil B 589nm	64.39(15)	63.615	1.52071	1.52071	3/5/2001	01:22
10/1.4	UWE Bristol	Oil B 589nm	64.27(68)	63.465	1.52076	1.52076	3/5/2001	01:22
11/1.1	UWE Bristol	Oil B 589nm	64.05(18)	63.195	1.52086	1.52086	3/5/2001	01:30
11/1.2	UWE Bristol	Oil B 589nm	64.11(33)	63.275	1.52083	1.52083	3/5/2001	01:30
11/1.3	UWE Bristol	Oil B 589nm	63.80(25)	62.87	1.52098	1.52098	3/5/2001	01:30

11/1.4	UWE Bristol	Oil B 589nm	63.72(29)	62.88	1.52097	1.52097	3/5/2001	01:30
12/1.1	UWE Bristol	Oil B 589nm	63.71(27)	62.95	1.52095	1.52095	3/5/2001	01:39
12/1.2	UWE Bristol	Oil B 589nm	64.56(30)	63.685	1.52068	1.52068	3/5/2001	01:39
12/1.3	UWE Bristol	Oil B 589nm	63.96(52)	63.13	1.52088	1.52088	3/5/2001	01:39
12/1.4	UWE Bristol	Oil B 589nm	63.93(38)	63.07	1.5209	1.52090	3/5/2001	01:39
Mean of 46 Samples: 63.55 Range: 62.87 - 64.18 SD: 0.321								
1.52073 Range: 1.52050 - 1.52098 SD: 0.0001174								

Control Sample AuVW03: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	64.09(90)	63.395	1.52079	1.52079	1/27/2009	13:44
1/1.2	UWE Bristol	Oil B 589nm	64.00(89)	63.3	1.52082	1.52082	1/27/2009	13:44
1/1.3	UWE Bristol	Oil B 589nm	63.99(89)	63.305	1.52082	1.52082	1/27/2009	13:44
1/1.4	UWE Bristol	Oil B 589nm	63.92(89)	63.245	1.52084	1.52084	1/27/2009	13:44
2/1.1	UWE Bristol	Oil B 589nm	63.98(99)	63.3	1.52082	1.52082	1/27/2009	13:51
2/1.2	UWE Bristol	Oil B 589nm	63.92(99)	63.225	1.52085	1.52085	1/27/2009	13:51
2/1.3	UWE Bristol	Oil B 589nm	64.01(73)	63.315	1.52082	1.52082	1/27/2009	13:51
2/1.4	UWE Bristol	Oil B 589nm	64.27(99)	63.59	1.52071	1.52071	1/27/2009	13:51
3/1.1	UWE Bristol	Oil B 589nm	64.45(99)	63.76	1.52065	1.52065	1/27/2009	14:02
3/1.2	UWE Bristol	Oil B 589nm	64.15(99)	63.455	1.52076	1.52076	1/27/2009	14:02
3/1.3	UWE Bristol	Oil B 589nm	63.89(99)	63.195	1.52086	1.52086	1/27/2009	14:02
3/1.4	UWE Bristol	Oil B 589nm	64.12(99)	63.41	1.52078	1.52078	1/27/2009	14:02
4/1.1	UWE Bristol	Oil B 589nm	64.42(72)	63.51	1.52074	1.52074	2/18/2009	11:13
4/1.2	UWE Bristol	Oil B 589nm	64.38(96)	63.46	1.52076	1.52076	2/18/2009	11:13
4/1.3	UWE Bristol	Oil B 589nm	64.30(99)	63.4	1.52078	1.52078	2/18/2009	11:13
4/1.4	UWE Bristol	Oil B 589nm	64.36(99)	63.445	1.52077	1.52077	2/18/2009	11:13
5/1.1	UWE Bristol	Oil B 589nm	64.15(90)	63.255	1.52084	1.52084	2/18/2009	11:22
5/1.2	UWE Bristol	Oil B 589nm	64.09(95)	63.215	1.52085	1.52085	2/18/2009	11:22
5/1.3	UWE Bristol	Oil B 589nm	64.09(99)	63.225	1.52085	1.52085	2/18/2009	11:22
5/1.4	UWE Bristol	Oil B 589nm	64.15(99)	63.28	1.52083	1.52083	2/18/2009	11:22
6/1.1	UWE Bristol	Oil B 589nm	64.25(60)	63.29	1.52082	1.52082	2/18/2009	11:45

6/1.2	UWE Bristol	Oil B 589nm	64.28(84)	63.31	1.52082	1.52082	2/18/2009	11:45
6/1.3	UWE Bristol	Oil B 589nm	64.18(83)	63.225	1.52085	1.52085	2/18/2009	11:45
6/1.4	UWE Bristol	Oil B 589nm	64.08(60)	63.135	1.52088	1.52088	2/18/2009	11:45
7/1.1	UWE Bristol	Oil B 589nm	64.04(59)	63.115	1.52089	1.52089	2/18/2009	12:24
7/1.2	UWE Bristol	Oil B 589nm	64.09(77)	63.175	1.52087	1.52087	2/18/2009	12:24
7/1.3	UWE Bristol	Oil B 589nm	64.09(62)	63.16	1.52087	1.52087	2/18/2009	12:24
7/1.4	UWE Bristol	Oil B 589nm	63.87(61)	62.925	1.52096	1.52096	2/18/2009	12:24
8/1.1	UWE Bristol	Oil B 589nm	63.60(59)	62.73	1.52103	1.52103	2/18/2009	12:44
8/1.2	UWE Bristol	Oil B 589nm	64.07(73)	63.185	1.52086	1.52086	2/18/2009	12:44
8/1.3	UWE Bristol	Oil B 589nm	64.34(84)	63.505	1.52075	1.52075	2/18/2009	12:44
8/1.4	UWE Bristol	Oil B 589nm	64.26(95)	63.405	1.52078	1.52078	2/18/2009	12:44
9/1.1	UWE Bristol	Oil B 589nm	64.04(34)	63.125	1.52089	1.52089	2/18/2009	12:56
9/1.2	UWE Bristol	Oil B 589nm	64.03(44)	63.12	1.52089	1.52089	2/18/2009	12:56
9/1.3	UWE Bristol	Oil B 589nm	64.28(37)	63.35	1.5208	1.52080	2/18/2009	12:56
9/1.4	UWE Bristol	Oil B 589nm	64.20(38)	63.285	1.52083	1.52083	2/18/2009	12:56
10/1.1	UWE Bristol	Oil B 589nm	63.97(99)	63.05	1.52091	1.52091	2/18/2009	13:06
10/1.2	UWE Bristol	Oil B 589nm	64.15(99)	63.23	1.52084	1.52084	2/18/2009	13:06
10/1.3	UWE Bristol	Oil B 589nm	64.19(99)	63.27	1.52083	1.52083	2/18/2009	13:06
10/1.4	UWE Bristol	Oil B 589nm	64.32(99)	63.395	1.52079	1.52079	2/18/2009	13:06
11/1.1	UWE Bristol	Oil B 589nm	64.09(88)	63.19	1.52086	1.52086	2/18/2009	13:17
11/1.2	UWE Bristol	Oil B 589nm	64.06(99)	63.15	1.52087	1.52087	2/18/2009	13:17
11/1.3	UWE Bristol	Oil B 589nm	64.00(95)	63.095	1.5209	1.52090	2/18/2009	13:17
11/1.4	UWE Bristol	Oil B 589nm	63.81(55)	62.87	1.52098	1.52098	2/18/2009	13:17
12/1.1	UWE Bristol	Oil B 589nm	64.05(82)	63.155	1.52087	1.52087	2/18/2009	13:27
12/1.2	UWE Bristol	Oil B 589nm	64.00(85)	63.105	1.52089	1.52089	2/18/2009	13:27
12/1.3	UWE Bristol	Oil B 589nm	64.00(76)	63.105	1.52089	1.52089	2/18/2009	13:27
12/1.4	UWE Bristol	Oil B 589nm	63.88(87)	62.995	1.52093	1.52093	2/18/2009	13:27

Mean of 48 Samples: 63.25 Range: 62.73 - 63.76 SD: 0.181
1.52084 Range: 1.52065 - 1.52103 SD: 0.0000669

Control Sample AuVW04: car, Float Toughened

1/1.1	UWE Bristol	Oil B 589nm	65.13(99)	64.22	1.52048	1.52048	3/5/2001	01:52
1/1.2	UWE Bristol	Oil B 589nm	65.09(99)	64.195	1.52049	1.52049	3/5/2001	01:52
1/1.3	UWE Bristol	Oil B 589nm	65.19(99)	64.29	1.52046	1.52046	3/5/2001	01:52
1/1.4	UWE Bristol	Oil B 589nm	65.09(99)	64.185	1.5205	1.52050	3/5/2001	01:52
2/1.1	UWE Bristol	Oil B 589nm	65.37(85)	64.525	1.52037	1.52037	3/5/2001	02:00
2/1.2	UWE Bristol	Oil B 589nm	65.34(78)	64.46	1.52039	1.52039	3/5/2001	02:00
2/1.3	UWE Bristol	Oil B 589nm	65.48(99)	64.62	1.52034	1.52034	3/5/2001	02:00
2/1.4	UWE Bristol	Oil B 589nm	65.22(99)	64.35	1.52043	1.52043	3/5/2001	02:00
3/1.1	UWE Bristol	Oil B 589nm	65.36(73)	64.47	1.52039	1.52039	3/5/2001	02:06
3/1.2	UWE Bristol	Oil B 589nm	65.40(99)	64.475	1.52039	1.52039	3/5/2001	02:06
3/1.3	UWE Bristol	Oil B 589nm	65.34(99)	64.425	1.52041	1.52041	3/5/2001	02:06
3/1.4	UWE Bristol	Oil B 589nm	65.51(94)	64.595	1.52035	1.52035	3/5/2001	02:06
4/1.1	UWE Bristol	Oil B 589nm	65.71(46)	64.84	1.52025	1.52025	3/5/2001	02:16
4/1.2	UWE Bristol	Oil B 589nm	65.27(37)	64.455	1.5204	1.52040	3/5/2001	02:16
4/1.3	UWE Bristol	Oil B 589nm	65.28(32)	64.465	1.52039	1.52039	3/5/2001	02:16
4/1.4	UWE Bristol	Oil B 589nm	65.30(32)	64.43	1.52041	1.52041	3/5/2001	02:16
5/1.1	UWE Bristol	Oil B 589nm	64.81(26)	64.03	1.52055	1.52055	3/5/2001	02:26
5/1.2	UWE Bristol	Oil B 589nm	65.34(22)	64.47	1.52039	1.52039	3/5/2001	02:26
5/1.3	UWE Bristol	Oil B 589nm	65.09(24)	64.145	1.52051	1.52051	3/5/2001	02:26
5/1.4	UWE Bristol	Oil B 589nm	65.18(24)	64.32	1.52045	1.52045	3/5/2001	02:26
6/1.1	UWE Bristol	Oil B 589nm	65.30(30)	64.435	1.52041	1.52041	3/5/2001	02:33
6/1.2	UWE Bristol	Oil B 589nm	65.36(39)	64.505	1.52038	1.52038	3/5/2001	02:33
6/1.3	UWE Bristol	Oil B 589nm	65.13(65)	64.26	1.52047	1.52047	3/5/2001	02:33
6/1.4	UWE Bristol	Oil B 589nm	65.19(70)	64.265	1.52047	1.52047	3/5/2001	02:33
7/1.1	UWE Bristol	Oil B 589nm	65.48(88)	64.605	1.52034	1.52034	3/5/2001	02:43
7/1.2	UWE Bristol	Oil B 589nm	65.44(58)	64.555	1.52036	1.52036	3/5/2001	02:43
7/1.3	UWE Bristol	Oil B 589nm	65.53(55)	64.6	1.52034	1.52034	3/5/2001	02:43
7/1.4	UWE Bristol	Oil B 589nm	65.33(26)	64.33	1.52044	1.52044	3/5/2001	02:43
8/1.1	UWE Bristol	Oil B 589nm	65.36(85)	64.47	1.52039	1.52039	3/5/2001	02:51

8/1.2	UWE Bristol	Oil B 589nm	65.34(81)	64.42	1.52041	1.52041	3/5/2001	02:51
8/1.3	UWE Bristol	Oil B 589nm	65.38(84)	64.465	1.52039	1.52039	3/5/2001	02:51
8/1.4	UWE Bristol	Oil B 589nm	65.45(99)	64.54	1.52036	1.52036	3/5/2001	02:51
9/1.1	UWE Bristol	Oil B 589nm	65.41(27)	64.415	1.52041	1.52041	3/5/2001	02:58
9/1.2	UWE Bristol	Oil B 589nm	65.37(74)	64.395	1.52042	1.52042	3/5/2001	02:58
9/1.3	UWE Bristol	Oil B 589nm	65.51(78)	64.535	1.52037	1.52037	3/5/2001	02:58
9/1.4	UWE Bristol	Oil B 589nm	65.59(94)	64.63	1.52033	1.52033	3/5/2001	02:58
10/1.1	UWE Bristol	Oil B 589nm	65.33(64)	64.53	1.52037	1.52037	3/5/2001	03:09
10/1.2	UWE Bristol	Oil B 589nm	65.23(27)	64.405	1.52042	1.52042	3/5/2001	03:09
10/1.3	UWE Bristol	Oil B 589nm	65.25(26)	64.415	1.52041	1.52041	3/5/2001	03:09
10/1.4	UWE Bristol	Oil B 589nm	65.30(47)	64.46	1.52039	1.52039	3/5/2001	03:09
11/1.1	UWE Bristol	Oil B 589nm	65.08(25)	64.265	1.52047	1.52047	3/5/2001	03:16
11/1.2	UWE Bristol	Oil B 589nm	65.22(29)	64.28	1.52046	1.52046	3/5/2001	03:16
11/1.3	UWE Bristol	Oil B 589nm	64.66(37)	63.99	1.52057	1.52057	3/5/2001	03:16
11/1.4	UWE Bristol	Oil B 589nm	65.23(30)	64.3	1.52045	1.52045	3/5/2001	03:16
12/1.1	UWE Bristol	Oil B 589nm	65.32(30)	64.465	1.52039	1.52039	3/5/2001	03:24
12/1.2	UWE Bristol	Oil B 589nm	65.48(28)	64.61	1.52034	1.52034	3/5/2001	03:24
12/1.3	UWE Bristol	Oil B 589nm	65.09(59)	64.27	1.52046	1.52046	3/5/2001	03:24
12/1.4	UWE Bristol	Oil B 589nm	65.38(41)	64.545	1.52036	1.52036	3/5/2001	03:24

Mean of 48 Samples: 64.42 Range: 63.99 - 64.84 SD: 0.160
1.52041 Range: 1.52025 - 1.52057 SD: 0.0000595

Control Sample AuFIA01: car, Float Laminated

1/1.1	UWE Bristol	Oil B 589nm	53.79(7)	52.855	1.52465	1.52465	3/21/2001	00:28
1/1.2	UWE Bristol	Oil B 589nm	54.04(14)	53.125	1.52455	1.52455	3/21/2001	00:28
1/1.3	UWE Bristol	Oil B 589nm	53.84(22)	52.925	1.52462	1.52462	3/21/2001	00:28
1/1.4	UWE Bristol	Oil B 589nm	53.82(23)	52.905	1.52463	1.52463	3/21/2001	00:28
2/1.1	UWE Bristol	Oil B 589nm	54.18(31)	53.26	1.5245	1.52450	3/21/2001	00:40
2/1.2	UWE Bristol	Oil B 589nm	54.00(29)	53.055	1.52457	1.52457	3/21/2001	00:40
2/1.3	UWE Bristol	Oil B 589nm	54.10(24)	53.165	1.52453	1.52453	3/21/2001	00:40

2/1.4	UWE Bristol	Oil B 589nm	54.14(23)	53.18	1.52453	1.52453	3/21/2001	00:40
3/1.1	UWE Bristol	Oil B 589nm	53.92(97)	52.995	1.5246	1.52460	3/21/2001	00:52
3/1.2	UWE Bristol	Oil B 589nm	54.01(99)	53.07	1.52457	1.52457	3/21/2001	00:52
3/1.3	UWE Bristol	Oil B 589nm	54.02(99)	53.08	1.52456	1.52456	3/21/2001	00:52
3/1.4	UWE Bristol	Oil B 589nm	53.92(62)	52.995	1.5246	1.52460	3/21/2001	00:52
4/1.1	UWE Bristol	Oil B 589nm	54.21(99)	53.24	1.5245	1.52450	3/21/2001	01:01
4/1.2	UWE Bristol	Oil B 589nm	54.14(15)	53.195	1.52452	1.52452	3/21/2001	01:01
4/1.3	UWE Bristol	Oil B 589nm	53.96(22)	52.985	1.5246	1.52460	3/21/2001	01:01
4/1.4	UWE Bristol	Oil B 589nm	53.81(23)	52.885	1.52464	1.52464	3/21/2001	01:01
5/1.1	UWE Bristol	Oil B 589nm	54.13(99)	53.18	1.52453	1.52453	3/21/2001	01:11
5/1.2	UWE Bristol	Oil B 589nm	54.11(99)	53.155	1.52454	1.52454	3/21/2001	01:11
5/1.3	UWE Bristol	Oil B 589nm	54.11(99)	53.165	1.52453	1.52453	3/21/2001	01:11
5/1.4	UWE Bristol	Oil B 589nm	54.07(99)	53.12	1.52455	1.52455	3/21/2001	01:11
6/1.1	UWE Bristol	Oil B 589nm	53.77(42)	52.8	1.52467	1.52467	3/21/2001	01:21
6/1.2	UWE Bristol	Oil B 589nm	53.77(33)	52.76	1.52468	1.52468	3/21/2001	01:21
6/1.3	UWE Bristol	Oil B 589nm	54.08(95)	53.1	1.52456	1.52456	3/21/2001	01:21
6/1.4	UWE Bristol	Oil B 589nm	53.98(79)	53	1.52459	1.52459	3/21/2001	01:21
7/1.1	UWE Bristol	Oil B 589nm	53.91(28)	53.11	1.52455	1.52455	3/21/2001	01:29
7/1.2	UWE Bristol	Oil B 589nm	53.87(30)	53.085	1.52456	1.52456	3/21/2001	01:29
7/1.3	UWE Bristol	Oil B 589nm	53.94(39)	53.22	1.52451	1.52451	3/21/2001	01:29
7/1.4	UWE Bristol	Oil B 589nm	53.90(11)	53.055	1.52457	1.52457	3/21/2001	01:29
8/1.1	UWE Bristol	Oil B 589nm	54.10(56)	53.32	1.52448	1.52448	3/21/2001	01:41
8/1.2	UWE Bristol	Oil B 589nm	54.02(99)	53.215	1.52452	1.52452	3/21/2001	01:41
8/1.3	UWE Bristol	Oil B 589nm	54.05(99)	53.23	1.52451	1.52451	3/21/2001	01:41
8/1.4	UWE Bristol	Oil B 589nm	53.96(99)	53.165	1.52453	1.52453	3/21/2001	01:41
9/1.1	UWE Bristol	Oil B 589nm	53.93(21)	53.24	1.5245	1.52450	3/21/2001	01:49
9/1.2	UWE Bristol	Oil B 589nm	53.95(83)	53.21	1.52452	1.52452	3/21/2001	01:49
9/1.3	UWE Bristol	Oil B 589nm	54.08(40)	53.285	1.52449	1.52449	3/21/2001	01:49
9/1.4	UWE Bristol	Oil B 589nm	53.94(87)	53.16	1.52453	1.52453	3/21/2001	01:49
10/1.1	UWE Bristol	Oil B 589nm	53.91(28)	53.015	1.52459	1.52459	3/21/2001	02:01

10/1.2	UWE Bristol	Oil B 589nm	54.05(43)	53.1	1.52456	1.52456	3/21/2001	02:01
10/1.3	UWE Bristol	Oil B 589nm	53.92(44)	52.99	1.5246	1.52460	3/21/2001	02:01
10/1.4	UWE Bristol	Oil B 589nm	53.98(72)	53.04	1.52458	1.52458	3/21/2001	02:01
11/1.1	UWE Bristol	Oil B 589nm	54.05(99)	53.08	1.52456	1.52456	3/21/2001	02:10
11/1.2	UWE Bristol	Oil B 589nm	55.48(87)	54.495	1.52405	1.52405	3/21/2001	02:10
11/1.3	UWE Bristol	Oil B 589nm	54.37(45)	53.41	1.52444	1.52444	3/21/2001	02:10
11/1.4	UWE Bristol	Oil B 589nm	54.37(34)	53.415	1.52444	1.52444	3/21/2001	02:10
12/1.1	UWE Bristol	Oil B 589nm	54.16(62)	53.185	1.52453	1.52453	3/21/2001	02:26
12/1.2	UWE Bristol	Oil B 589nm	54.05(99)	53.06	1.52457	1.52457	3/21/2001	02:26
12/1.3	UWE Bristol	Oil B 589nm	54.06(99)	53.1	1.52456	1.52456	3/21/2001	02:26
12/1.4	UWE Bristol	Oil B 589nm	54.10(74)	53.125	1.52455	1.52455	3/21/2001	02:26

Mean of 48 Samples: 53.14 Range: 52.76 - 54.49 SD: 0.241
1.52454 Range: 1.52405 - 1.52468 SD: 0.0000883

Control Sample AuCIT01: car, Float Laminated

1/1.1	UWE Bristol	Oil B 589nm	68.28(73)	67.345	1.51934	1.51934	3/21/2001	02:39
1/1.2	UWE Bristol	Oil B 589nm	68.31(58)	67.37	1.51933	1.51933	3/21/2001	02:39
1/1.3	UWE Bristol	Oil B 589nm	68.38(52)	67.455	1.5193	1.51930	3/21/2001	02:39
1/1.4	UWE Bristol	Oil B 589nm	68.33(22)	67.385	1.51932	1.51932	3/21/2001	02:39
2/1.1	UWE Bristol	Oil B 589nm	68.41(73)	67.495	1.51928	1.51928	3/21/2001	02:47
2/1.2	UWE Bristol	Oil B 589nm	68.31(82)	67.375	1.51933	1.51933	3/21/2001	02:47
2/1.3	UWE Bristol	Oil B 589nm	68.35(66)	67.435	1.51931	1.51931	3/21/2001	02:47
2/1.4	UWE Bristol	Oil B 589nm	68.37(85)	67.44	1.5193	1.51930	3/21/2001	02:47
3/1.1	UWE Bristol	Oil B 589nm	68.33(98)	67.385	1.51932	1.51932	3/21/2001	02:55
3/1.2	UWE Bristol	Oil B 589nm	68.36(90)	67.42	1.51931	1.51931	3/21/2001	02:55
3/1.3	UWE Bristol	Oil B 589nm	68.48(80)	67.55	1.51926	1.51926	3/21/2001	02:55
3/1.4	UWE Bristol	Oil B 589nm	68.35(99)	67.41	1.51931	1.51931	3/21/2001	02:55
4/1.1	UWE Bristol	Oil B 589nm	68.27(33)	67.345	1.51934	1.51934	3/21/2001	03:04
4/1.2	UWE Bristol	Oil B 589nm	68.73(53)	67.73	1.5192	1.51920	3/21/2001	03:04
4/1.3	UWE Bristol	Oil B 589nm	68.43(99)	67.485	1.51929	1.51929	3/21/2001	03:04

4/1.4	UWE Bristol	Oil B 589nm	68.36(99)	67.41	1.51931	1.51931	3/21/2001	03:04
5/1.1	UWE Bristol	Oil B 589nm	68.50(99)	67.56	1.51926	1.51926	3/21/2001	03:14
5/1.2	UWE Bristol	Oil B 589nm	68.43(99)	67.49	1.51928	1.51928	3/21/2001	03:14
5/1.3	UWE Bristol	Oil B 589nm	68.46(86)	67.51	1.51928	1.51928	3/21/2001	03:14
5/1.4	UWE Bristol	Oil B 589nm	68.36(64)	67.255	1.51937	1.51937	3/21/2001	03:14
6/1.1	UWE Bristol	Oil B 589nm	68.48(94)	67.51	1.51928	1.51928	3/21/2001	03:22
6/1.2	UWE Bristol	Oil B 589nm	68.18(21)	67.205	1.51939	1.51939	3/21/2001	03:22
6/1.3	UWE Bristol	Oil B 589nm	68.36(78)	67.435	1.51931	1.51931	3/21/2001	03:22
6/1.4	UWE Bristol	Oil B 589nm	68.41(67)	67.47	1.51929	1.51929	3/21/2001	03:22
7/1.1	UWE Bristol	Oil B 589nm	68.39(17)	67.54	1.51927	1.51927	3/21/2001	03:33
7/1.2	UWE Bristol	Oil B 589nm	68.26(59)	67.425	1.51931	1.51931	3/21/2001	03:33
7/1.3	UWE Bristol	Oil B 589nm	68.38(48)	67.52	1.51927	1.51927	3/21/2001	03:33
7/1.4	UWE Bristol	Oil B 589nm	68.25(99)	67.43	1.51931	1.51931	3/21/2001	03:33
8/1.1	UWE Bristol	Oil B 589nm	68.28(31)	67.445	1.5193	1.51930	3/21/2001	03:42
8/1.2	UWE Bristol	Oil B 589nm	68.35(99)	67.51	1.51928	1.51928	3/21/2001	03:42
8/1.3	UWE Bristol	Oil B 589nm	68.50(99)	67.67	1.51922	1.51922	3/21/2001	03:42
8/1.4	UWE Bristol	Oil B 589nm	68.46(77)	67.635	1.51923	1.51923	3/21/2001	03:42
9/1.1	UWE Bristol	Oil B 589nm	68.33(68)	67.495	1.51928	1.51928	3/21/2001	03:51
9/1.2	UWE Bristol	Oil B 589nm	68.37(82)	67.53	1.51927	1.51927	3/21/2001	03:51
9/1.3	UWE Bristol	Oil B 589nm	68.34(82)	67.475	1.51929	1.51929	3/21/2001	03:51
9/1.4	UWE Bristol	Oil B 589nm	68.35(48)	67.495	1.51928	1.51928	3/21/2001	03:51
10/1.1	UWE Bristol	Oil B 589nm	68.21(84)	67.275	1.51936	1.51936	3/21/2001	03:59
10/1.2	UWE Bristol	Oil B 589nm	68.33(99)	67.415	1.51931	1.51931	3/21/2001	03:59
10/1.3	UWE Bristol	Oil B 589nm	68.31(99)	67.395	1.51932	1.51932	3/21/2001	03:59
10/1.4	UWE Bristol	Oil B 589nm	68.22(99)	67.29	1.51936	1.51936	3/21/2001	03:59
11/1.1	UWE Bristol	Oil B 589nm	68.57(35)	67.665	1.51922	1.51922	3/21/2001	04:19
11/1.2	UWE Bristol	Oil B 589nm	68.32(28)	67.43	1.51931	1.51931	3/21/2001	04:19
11/1.3	UWE Bristol	Oil B 589nm	68.36(46)	67.485	1.51929	1.51929	3/21/2001	04:19
11/1.4	UWE Bristol	Oil B 589nm	68.38(49)	67.46	1.5193	1.51930	3/21/2001	04:19
12/1.1	UWE Bristol	Oil B 589nm	68.41(99)	67.455	1.5193	1.51930	3/21/2001	04:29

12/1.2	UWE Bristol	Oil B 589nm	68.36(99)	67.41	1.51931	1.51931	3/21/2001	04:29
12/1.3	UWE Bristol	Oil B 589nm	68.40(55)	67.44	1.5193	1.51930	3/21/2001	04:29
12/1.4	UWE Bristol	Oil B 589nm	68.41(30)	67.455	1.5193	1.51930	3/21/2001	04:29
Mean of 48 Samples: 67.45 Range: 67.21 - 67.73 SD: 0.100								
1.51930 Range: 1.51920 - 1.51939 SD: 0.0000365								

Control Sample AuTOY01: car, Float Laminated

1/1.1	UWE Bristol	Oil B 589nm	67.39(64)	66.445	1.51967	1.51967	3/21/2001	04:47
1/1.2	UWE Bristol	Oil B 589nm	67.34(99)	66.405	1.51968	1.51968	3/21/2001	04:47
1/1.3	UWE Bristol	Oil B 589nm	67.43(90)	66.47	1.51966	1.51966	3/21/2001	04:47
1/1.4	UWE Bristol	Oil B 589nm	67.42(99)	66.48	1.51965	1.51965	3/21/2001	04:47
2/1.1	UWE Bristol	Oil B 589nm	67.70(26)	66.805	1.51954	1.51954	3/21/2001	04:55
2/1.2	UWE Bristol	Oil B 589nm	67.39(50)	66.5	1.51965	1.51965	3/21/2001	04:55
2/1.3	UWE Bristol	Oil B 589nm	67.46(57)	66.56	1.51962	1.51962	3/21/2001	04:55
2/1.4	UWE Bristol	Oil B 589nm	67.48(31)	66.6	1.51961	1.51961	3/21/2001	04:55
3/1.1	UWE Bristol	Oil B 589nm	67.37(24)	66.525	1.51964	1.51964	3/21/2001	05:03
3/1.2	UWE Bristol	Oil B 589nm	67.29(7)	66.375	1.51969	1.51969	3/21/2001	05:03
3/1.3	UWE Bristol	Oil B 589nm	67.55(22)	66.71	1.51957	1.51957	3/21/2001	05:03
3/1.4	UWE Bristol	Oil B 589nm	67.27(16)	66.405	1.51968	1.51968	3/21/2001	05:03
4/1.1	UWE Bristol	Oil B 589nm	67.14(8)	66.21	1.51975	1.51975	3/21/2001	05:12
4/1.2	UWE Bristol	Oil B 589nm	66.94(11)	66.035	1.51982	1.51982	3/21/2001	05:12
4/1.3	UWE Bristol	Oil B 589nm	67.08(14)	66.155	1.51977	1.51977	3/21/2001	05:12
4/1.4	UWE Bristol	Oil B 589nm	67.23(26)	66.37	1.51969	1.51969	3/21/2001	05:12
5/1.1	UWE Bristol	Oil B 589nm	67.50(99)	66.63	1.5196	1.51960	3/21/2001	05:20
5/1.2	UWE Bristol	Oil B 589nm	67.52(99)	66.665	1.51959	1.51959	3/21/2001	05:20
5/1.3	UWE Bristol	Oil B 589nm	67.48(65)	66.62	1.5196	1.51960	3/21/2001	05:20
5/1.4	UWE Bristol	Oil B 589nm	67.81(65)	66.925	1.51949	1.51949	3/21/2001	05:20
6/1.1	UWE Bristol	Oil B 589nm	67.54(40)	66.625	1.5196	1.51960	3/21/2001	05:28
6/1.2	UWE Bristol	Oil B 589nm	67.46(84)	66.56	1.51962	1.51962	3/21/2001	05:28
6/1.3	UWE Bristol	Oil B 589nm	67.40(94)	66.515	1.51964	1.51964	3/21/2001	05:28

6/1.4	UWE Bristol	Oil B 589nm	67.33(99)	66.44	1.51967	1.51967	3/21/2001	05:28
7/1.1	UWE Bristol	Oil B 589nm	67.28(30)	66.48	1.51965	1.51965	3/21/2001	05:38
7/1.2	UWE Bristol	Oil B 589nm	67.44(33)	66.625	1.5196	1.51960	3/21/2001	05:38
7/1.3	UWE Bristol	Oil B 589nm	67.21(12)	66.425	1.51968	1.51968	3/21/2001	05:38
7/1.4	UWE Bristol	Oil B 589nm	67.34(17)	66.51	1.51964	1.51964	3/21/2001	05:38
8/1.1	UWE Bristol	Oil B 589nm	67.59(10)	66.65	1.51959	1.51959	3/21/2001	05:45
8/1.2	UWE Bristol	Oil B 589nm	67.77(10)	66.85	1.51952	1.51952	3/21/2001	05:45
8/1.3	UWE Bristol	Oil B 589nm	67.84(9)	66.88	1.51951	1.51951	3/21/2001	05:45
8/1.4	UWE Bristol	Oil B 589nm	67.57(9)	66.705	1.51957	1.51957	3/21/2001	05:45
9/1.1	UWE Bristol	Oil B 589nm	67.44(99)	66.6	1.51961	1.51961	3/21/2001	05:53
9/1.2	UWE Bristol	Oil B 589nm	67.42(99)	66.595	1.51961	1.51961	3/21/2001	05:53
9/1.3	UWE Bristol	Oil B 589nm	67.37(99)	66.535	1.51964	1.51964	3/21/2001	05:53
9/1.4	UWE Bristol	Oil B 589nm	67.39(99)	66.575	1.51962	1.51962	3/21/2001	05:53
10/1.1	UWE Bristol	Oil B 589nm	64.03(33)	63.185	1.52086	1.52086	3/21/2001	06:01
10/1.2	UWE Bristol	Oil B 589nm	64.06(77)	63.23	1.52084	1.52084	3/21/2001	06:01
10/1.3	UWE Bristol	Oil B 589nm	64.20(37)	63.37	1.52079	1.52079	3/21/2001	06:01
10/1.4	UWE Bristol	Oil B 589nm	63.96(43)	63.125	1.52089	1.52089	3/21/2001	06:01
11/1.1	UWE Bristol	Oil B 589nm	68.50(13)	67.61	1.51924	1.51924	3/21/2001	06:11
11/1.2	UWE Bristol	Oil B 589nm	64.23(99)	63.345	1.5208	1.52080	3/21/2001	06:11
11/1.3	UWE Bristol	Oil B 589nm	67.78(99)	66.68	1.51958	1.51958	3/21/2001	06:11
11/1.4	UWE Bristol	Oil B 589nm	68.09(91)	67.41	1.51931	1.51931	3/21/2001	06:11
12/1.1	UWE Bristol	Oil B 589nm	64.17(99)	63.305	1.52082	1.52082	3/21/2001	06:17
12/1.2	UWE Bristol	Oil B 589nm	64.07(99)	63.195	1.52086	1.52086	3/21/2001	06:17
12/1.3	UWE Bristol	Oil B 589nm	64.09(92)	63.24	1.52084	1.52084	3/21/2001	06:17
12/1.4	UWE Bristol	Oil B 589nm	64.04(60)	63.17	1.52087	1.52087	3/21/2001	06:17
Mean of 48 Samples: 65.97 Range: 63.13 - 67.61 SD: 1.333								
1.51984 Range: 1.51924 - 1.52089 SD: 0.0004886								