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CV NEWS LETTER 21

Comité Technique du Corpus Vitrearum

Physics, University of York

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CONTENTS

1 GENERAL

1.1 BRITISH TECHNICAL COMMITTEE

The new statutes of the Corpus Vitrearum, adopted in Paris on 12 September 1975, contain in Clause IX the statement that each National Committee should be associated with the organisation for scientific research in its country. The British National Committee is, of course, already closely associated with the British Academy but the way then became open to seek a closer association with the Royal Society.

This closer association was welcomed by the Royal Society and a new joint committee has been set up, called THE BRITISH NATIONAL COMMITTEE FOR THE CONSERVATION OF STAINED GLASS. There are three representatives of the Royal Society:-

Professor Nicholas Kurti, CBE FRS, of the University of Oxford,
Dr D.S. Oliver, Director of Research and Development, Pilkington Brothers Ltd.,
Sir Gordon Sutherland, FRS, Master of Emmanuel College, Cambridge.

The representatives of the British Academy are:-

Dr Alan Borg, H.M. Tower of London, Editor for the National Committee,
Mr A.R. Dufty, CBE, H.M. Tower of London, Chairman of the National Committee,
Mr Dennis G. King, FSA, Stained glass conservator and restorer at Norwich,
Professor Roy Newton, OBE, Président of the Comité Technique, and a Vice President of the Corpus,
Dr Neville Williams, Secretary of the British Academy, and of the National Committee.

The old Committee, the Technical Sub-committee of the British Committee of the CVMA, has now been wound up and the members thanked for their services. The new Committee will have its first meeting in September and it is expected that the support of the two premier Societies in the U.K., one for the humanities and the other for the natural sciences, will greatly strengthen the technical studies on stained glass, not only of the British National Committee but also of the Comité Technique.

1.2 THE 10th COLLOQUIUM OF THE CORPUS VITREARUM

It is expected that the 10th Colloquium will be held in Stuttgart, Bern, and Freiburg-im-Breisgau between 23rd and 27th May 1977. Art-historical problems will be discussed in Stuttgart on 23/24 May, in conjunction with the Staufer Exhibition. It is hoped that a meeting of the Comité Technique can be held simultaneously, but in Bern. On 26/27 May both groups may come together in Freiburg-in-Breisgau for a general meeting. Fuller details will be given when the rather complicated financial arrangements have been finalised.

1.3 THE BLUE GLASS AT CHARTRES

The predominance of the blue colour in the west windows at Chartres Cathedral was discussed by Dr Eva Frodl-Kraft in Section 2 of N.L. No.20 and I am grateful to Mr Dieter Goldkuhle, of Reston, Virginia, USA, for kindly drawing my attention to an article by Robert Sowers in the 1966 issue of '<u>The Art Bulletin</u>' (Vol 48, 218-222).

The article is entitled "ON THE BLUES IN CHARTRES" and the author states "As I studied the windows in detail with binoculars I became aware that .... it is the blue alone which stands out in absolute clarity, clear and practically unblemished, while nearly all of the other colors are rather heavily obscured with patina." ".... from the outside .... this blue glass .... is practically free from the ash-coloured patina that generally covers the surfaces of mediaeval glass .... Is it possible then, that when this window was new, and all of the colors in it were as clear as the blue, that it was not a 'blue' window at all ...., that it appears blue now neither because of the superior radiation of blue glass, as Viollet-le-Duc thought (in about 1860), nor for the reasons proposed by James Johnson (in his 'Radiance of Chartres' 1965) but rather because of the more advanced deterioration of the other glass?" ".... it is difficult to understand how just this blue glass and it alone throughout the west windows could have survived so singularly unravaged by the marks of time.".

Thanks to the help of M J.M. Bettembourg, Dr G.A. Cox of the University of York has been able to analyse non-destructively some blue glass from the west windows at Chartres. The results are given as analyses Nos 103 and 105 in the tables in Section 5 of this News Letter. It can be seen that these pieces of blue glass (N.B. not all the blue glass at Chartres) are a soda glass (9.5% and 14.3% of soda) and they have a moderate lime content (7.9 and 8.1% CaO). They are thus quite unlike the other samples of glass from Chartres analysed by Dr Cox at the same time (Nos 104, 106 and 107) which are potash glasses with 19.8 to 21.2% of lime. (Note: it is the high lime content which gives the low durability, rather than the potash content.) Thus the very durable blue glass from Chartres is not unlike the 12th century blue glass from York Minster (analyses Nos 2 and 3 in the table).

1.4 DOW-CORNING MATERIALS FOR CONSERVATION OF STAINED GLASS

1.4.1 "Protective Resins" for coating glass

Thanks to the kind interest taken by Mr Severn Joyce, Vice-President for Purchases and Transportation of Owens-Corning Fiberglas Corporation, in Toledo, Ohio, and his concern for the restoration of Canterbury Cathedral, some experimental work on possible "protective resins" made by Dow-Corning Ltd will be undertaken at their laboratories in Barry, Glamorgan, South Wales.

At present the studies are exploratory in nature but they will involve Soxhlet extraction tests, similar to those used by me in Sheffield in 1973, and by M Bettembourg in Paris, and the simulated medieval glass will be British Glass No.2. This proposed work by Dow-Corning Ltd is greatly appreciated, as is the interest taken by Mr Severn Joyce.

1.4.2 Silicone sealants and attack on lead "cames"

Item 1.2 of N.L. No.20 contained a note about a Dow-Corning oxime-curing sealant which was recommended because it would not release the objectionable acetic acid which has been found to produce an attack on the leads. I have now been told that this material is no longer on the market, but an even better material is available and it has been given some preliminary tests. Mr C. Naylor, of Dow-Corning Technical Service and Development department for Encapsulants and Sealants, Parc Industriel, B-6198 Seneffe, Belgium, has written to say that he has carried out some satisfactory tests on the following lines.

Ours = 781

He believes that Dow-Corning Silastic RTV (= Room Temperature Vulcanising) 3140 (clear) silicone sealant will be preferable to the acetoxy-types; it uses an alkoxy cross-linker and cures on exposure to moisture, liberating only a small quantity of an aliphatic alcohol. He also pointed out that Silastic RTV 3140 is a "liquid" and it is "flowable" but if a viscous material is preferred, then Silastic RTV 3144 is a "non-slumping" product. If a white product is desired, instead of a clear one, then Silastic RTV 738 can be used.

It will be necessary to use a primer (D.C. 1200) in order to obtain the best adhesion to both glass and lead when using RTV 3140 or RTV 3144. In the case of the lead it will be necessary to remove all surface dirt, the lead-oxide film, and grease, if necessary by abrasion (using emery paper or glass paper), followed by a wash with acetone. (RGN - acetone is highly inflammable and if substantial quantities are used there may be a fire-hazard. If it is desired to avoid all risks of fire, the I.C.I. solvent "Genklene" can be used instead.) The glass may have to be degreased if it is not absolutely clean. The primer D.C. 1200 needs at least 15 minutes for drying in air, and the treated surfaces should not be left exposed for more than 4 hours before applying the RTV 3140.

1.5 DETECTION OF SULPHITES (NOT SULPHATES) ON WEATHERED GLASS

In his interesting article on the part which sulphur dioxide may play in the weathering of medieval glass (see item 3 of N.L. No.20), Mr N.H. Ray discussed the possibility that acid sulphites (N.B. not sulphates) might be present as an intermediate step. Those who are studying the weathering of glass may therefore wish to be able to make tests for the presence of sulphites. Mr Ray has therefore kindly sent me the following note.

Sulphites can be detected in the presence of sulphate by their reaction with ferric ferricyanide giving Prussian Blue. I made a dilute aqueous solution of potassium ferricyanide and added a slight excess of aqueous ferric chloride. The resulting solution should be reddish yellow; if there is any sign of a blue precipitate (which arises from ferrous ion impurities in the reagents) it must be discarded and prepared again from purer materials. I next took a soda-glass microscope slide and made some scratches on it with a diamond. I then immersed the slide in an aqueous solution of sodium sulphite, allowed it to drain, removed surplus solution from the surface with filter paper, and left it to dry. I then poured a solution of sodium sulphate over the slide so that the surface was covered and allowed it to dry so that the whole of the slide was coated with sulphate, but in the scratches there would be a small amount of sulphite.

Finally I painted the ferric ferricyanide solution on to the slide with a small brush and after 10 minutes I examined the slide with a low-power microscope. Most of the slide was covered with a yellow deposit, but in the scratches there were clearly visible blue zones. Gentle washing of the slide with water removed the yellow-deposit, leaving the blue pigment in the scratch marks. This reaction is only given by anions that can reduce Fe^{III} to Fe^{II} in mildly acidic solution, and I think it should be applicable to a stained-glass window with suitable adaptation of the technique described.

1.6 SODA-GLASSES FROM PHRYGIA

In Section 5.3.1 of N.L. No.20 it was stated that Dr Bauer had analysed two pieces of 12th century soda glass from Phrygia; the analytical results are now given as Nos 97 and 98 in the tables in Section 5.

2 CONTRARY OPINIONS

Dr Wilhelm Bauer, of Vienna, has kindly sent me the following note: "Mr Cole's statement, in item 2 of N.L. No.19, was the first time I had known the full details of his experimental technique, using hydrofluoric acid for the so-called 'acid-polishing' process. Until that time I had known only the description given on page 6, lines 3 and 4, of the German version of N.L. No.13, which refers to the glass being 'rubbed' in 40% HF for 10 minutes.

"Obviously, Mr Cole's 'acid-polishing' procedure is quite different, both in the concentration of the acid used, and in the manipulative technique employed, which is related to various factors, such as the kinds of glass used and the types of corrosion.

"Thus it is quite possible that his 'acid-polishing' procedure could produce a polishing effect, at least with the so-called 'pitted' glasses. Further studies should be carried out to determine whether harmful effects eventually occur. In the airbrasive treatment of our glass we used powder No. 1/27, which is based on alumina."

Note by RGN - I am delighted to have this contribution from Dr Bauer, because it clears up a misunderstanding and also shows how easy it is to meet difficulties when making translations from another language! The English version of N.L. No.13, page 3, col.2, lines 18-20 discussed two pieces of glass which had been acid-polished by Mr Cole, using his procedure. The German version (p.6, lines 3 and 4) describes the samples as being "mit Säure abgerieben", which could give the impression that they had been rubbed under a solution of acid. I should add that Mr Cole does not now use hydrofluoric acid, partly because some of the pieces of glass (especially those which have a crust) are rapidly attacked and no polishing occurs, and partly because the acid is a dangerous one to use.

This section of the News Letter has been very useful in clearing up misunderstandings, or in putting forward other points of view. I therefore urge other readers to use this channel to put forward their point of view.

3 RESTORATIONS OF CATHEDRAL GLASS

Two articles have come to my notice for this issue, and it will be convenient to put them both in this section, including a contribution from me in section 3.2. My contribution may appear to be a "misfit" here, but I have kept it here in the hope that conservators and art-historians will take more notice of it than they have in the past!

3.1 THE PRINCIPLES OF CONSERVATION OF MEDIEVAL STAINED GLASS WINDOWS

This is an annotated translation of a paper read by Frau Dr Eva Frodl-Kraft at a meeting of cathedral architects and clerks of works, held in Vienna from 2nd to 5th June 1976.

3.1.1 Introduction

The author points out that we are faced with an alarming situation regarding our medieval stained glass. In every country where detailed investigations have been carried out (in practice, this is wherever such glass has survived) conservation work has turned out to be a last-minute operation (at Canterbury, York, Chartres and Regensburg). In addition, many old photographs show that there has been a frightening acceleration in the process of decay, especially since the last war. There are three reasons for this:-

(a) Natural weathering, which begins as soon as the window has been installed. Some windows have been exposed to rain, frost and wind for considerably more than 500 years, and they are now beginning to fall to pieces.

(b) The general deterioration of the environment; the build-up of harmful substances in the atmosphere, especially sulphur dioxide, stimulates and intensifies the weathering process through the formation of sulphuric acid with water. (RGN - more evidence is appearing - such as item 3 of N.L. No.21 - that small amounts of sulphur dioxide and sulphuric acid in the atmosphere may actually reduce the deterioration of the glass! The reason given is that acid gases in the atmosphere can neutralise the harmful alkaline solutions produced by attack on the glass by water. Moreover, the sulphur dioxide concentrations in the atmosphere have been decreasing since about 1953. Carbon dioxide has certainly been increasing, and so have hydrocarbons and oxides of nitrogen but I have not seen any evidence that the last two play any part in the weathering process.)

(c) Unsatisfactory earlier restoration work, especially during the last century, has tended to break up the surface of the glass so that there are many more points at which weathering can start (as at Cologne Cathedral). Some of the glass removed from cathedrals during the last war, in order to protect it from bomb damage, was stored under very wet conditions and this has caused deterioration. The author points out a case in the Historisches Museum in Vienna where peeling of the paintwork has been caused by damp. (RGN - Another example is the medieval glass at Canterbury Cathedral which was stored in very wet conditions for 6 years and the glass was much damaged.)

Another bad practice is that of renewing the leads at each restoration; if an unsuitable alloy is used the window can bulge under the influence of wind and sun and the whole structure can become loose, as in the west windows of Chartres Cathedral.

3.1.2 What should be done now, and what can be achieved using current procedures?

Both conservation and restoration are essential procedures but it must be pointed out that the so-called "original condition" can now never be regained. Some of the glass has become much darker owing to the formation of opaque crusts, and some of the painted decoration has disappeared. Differently-coloured glasses have behaved in quite different ways due to their distinct differences in chemical composition.

(a) Conservation, or protection against further decay

The aim here is to slow down, or perhaps even stop, the weathering process and yet make the minimum amount of alteration to the glass. The main attacking agent (RGN - perhaps the only one!) is water and conservation techniques must eliminate future contact with water, either as rain on the outside face of the window or (above all) as condensed moisture on the inside face. Weathering is also promoted by sharp changes in temperature, as between night and day on south-facing windows, so these should be levelled out as much as possible.

Moisture can be eliminated, and the temperature range can be reduced, in two ways; for the whole window by using external protective glazing or, for parts of the window, by using lamination, or protective resins. Both approaches have advantages and disadvantages.

External protective glazing: (RGN - this is Isothermal glazing, see also 3.2 below.)

The principal advantage of this approach is that the window need not be altered in any way. It is simply moved inwards, towards the church, and a modern secondary window is put in its place although, in practice, the medieval window is usually restored in addition to being moved. (Only safety measures were undertaken at Regensburg.)

The disadvantages are that the aesthetic effect of the window is impaired, especially when viewed from outside the building, but in particularly bad cases the internal appearance may be impaired. Another disadvantage is that no protection is afforded against pollutants from within the church, such as soot from candles. The outer protective glazing must be properly maintained or it will develop cracks and holes which destroy its protective function.

There is some uncertainty about the true long-term effect of external protective glazing because it was developed only empirically and no example has yet been in existence for an extended period of time, (RGN - How effective is the ventilation? How nearly are the "isothermal" conditions achieved? How often does condensation occur? Are there any other disadvantages, such as entry of dust, flies, etc? We do not even know how to specify the "best" installation.) but a small start has been made in the systematic recording of data.

Laminating, or applying protective resins

These two approaches necessitate cleaning the glass by thorough removal of the weathering crusts ("patina") and consequently there is some "attack" on the window, i.e. more than the minimum required. The advantages and disadvantages of these two processes are therefore quite different from those considered above. Laminating the panel with a plastics interlayer (RGN - such as polyvinyl butyral, or the material used at Cologne in Jacobi's "safety-glass" method) has the advantage of providing both internal and external protection, and also greatly increased mechanical stability. The disadvantages are that the panel must be re-leaded (RGN - sometimes the leads are even discarded, to give a laminated panel which is devoid of leading) and hence the method should never be used if medieval leads have survived. There may be reduced "reversibility" if the interlayer has become crosslinked; there is great increase in weight (and hence load on the mullions). The general appearance is changed (although this is not as marked as in the case of external protective glazing) and the panel has highly reflective surfaces, increased brightness, and a different refractivity. There is still uncertainty over how the panels will behave after installation for many years (e.g. discolouration of the interlayer).

Protective resin coatings might well be satisfactory if inorganic protective films could be used, such as are used for coating optical glasses. (RGN - the serious difficulty here is that medieval window glasses have a coefficient of thermal expansion which is about twice that of optical glass, and it seems unlikely that durable inorganic coatings could have such a high expansion. The only materials which are suitable at the present time are plastics coatings (epoxides or acrylates).) The advantages are that application is easy and it can be used selectively (i.e. it need not be put on the whole window but only on the unweathered glass in the panels) and it is not necessary to remove the glass from the leads. The disadvantages are that the original appearance of the glass may be altered (although less so than with protective glazing or laminating); there is slight brightening of the window and there is some surface shine. There is uncertainty regarding the behaviour of the plastics film over long periods of time. (Will it prevent entry of moisture? Will it peel or tear or otherwise separate from the glass? Will it discolour?) Continual inspection of any treated window will therefore be necessary and in-situ tests have already been started in Austria.

Summary

There is no ideal method of protection. If the presence of moisture on the glass can effectively be prevented, the old controversy, as to whether to remove the "patina" (weathering crust) or to leave it, will become only secondary in importance, or even be reduced to the aesthetic problem of whether to recover any translucence of the glass which has been lost. However, it should be borne in mind that any process which involves cleaning, or removal of the weathering crusts, automatically involves some risk. In the case of mechanical cleaning any damage to the surface of the glass may produce a new point of attack for weathering to continue. In the case of chemical cleaning, the surface of the old glass is always porous and the cleaning fluid may penetrate to deeper layers where its reactions cannot be controlled.

(b) Restoration; or making good any damage to the glass, or any disruption of the artistic design

The original appearance of the glass has been altered by weathering, for example there may have been some loss of transparency due to the development of opaque crusts on the outside surface (or even on the inside), or by loss of painted decoration. If the outside crusts have made the window very dark, and perhaps have also altered the colour balance if some colours have crusted more than others, careful and partial removal of these crusts from the outside surface will improve the appearance. If (as in the Romanesque panels at Regensburg) there is an opaque crust on the inner surface of the glass, there is a grave problem in removing the crust without also disturbing the painted decoration. Sometimes it is obvious where painted decoration is missing but overpainting of the medieval glass must definitely be ruled out (a way around this is to do the replacement-painting on a thin colourless modern glass).

3.1.3 Restoration at Chartres

All the problems discussed above from a theoretical point of view have recently been solved in connection with a very famous monument, Chartres Cathedral. The controversy caused by the restoration of the three west windows, which date from the middle of the 12th century, has been taken up by the European press where, as a result of lack of understanding of the difficulties, it has been handled in a very inexpert and polemical manner. For this reason (the unfortunate publicity) and also because the "Chartres case" shows particularly clearly how complex the problems can be when restoring painted glass, Frau Dr Frodl-Kraft briefly discusses it here.

The following situation confronted the restorers:

(a) the panels were loose because poor modern leadwork had been used,

(b) serious crusting had affected most of the coloured glass, except for the famous "bleu de ciel", and hence the windows had become predominantly blue in colour.

Hence it was necessary to carry out mechanical fixing; protection against further weathering; and improvement of the appearance of the window by restoring the translucency of those glasses which had become opaque. The dominant position of these three great windows, in the architecture of the west facade, made it impossible to use external protective glazing and it was therefore necessary to use a protective resin (which had been selected as a result of laboratory tests); the resin was applied selectively - i.e. only to the glasses which had crusted badly.

As a result, the well-known image, handed down to us, has been changed. By restoring the translucency of the other colours the window has been made much brighter, the overall blue tone has gone, and there is a colour-balance again. Although this bright and colourful window contradicts the romantic idea of the stained glass at Chartres it does in fact come closer to the original appearance intended by the medieval glaziers.

Although the restoration work carried out is entirely justified from the point of view of conservation of historic monuments, and indeed was the only course at present open to the conservators, the idea of a "blue Chartres" had become so firmly fixed in the public imagination that it was easy, by skilful propaganda, to mobilise some public opinion against the restoration, and consequently to raise anxiety about conservation work in general.

In the final analysis the success of any type of restoration work, whatever its aim, depends on the relationship between scientific understanding of the background, and skilled craftsmanship. Thus an understanding of the nature of the weathering process is a prerequisite for effective work. Similarly, new methods of cleaning, or new materials, should be adopted only on the basis of reliable scientific and technological tests.

The responsibility for the success or failure of any conservation work cannot, however, be laid wholly at the door of science and technology. Even a method which is scientifically satisfactory can, if it is carried out carelessly, ruin a stained glass window. Moreover, some operations depend almost entirely on the craftsmanship of the restorer and his understanding of the aesthetics and iconography of the work. There are some skills, such as removal of the weathering crusts with the airbrasive, which should be entrusted only to skilled workers. When evaluating a restoration technique the determining factor is not its efficiency but the degree of protection which it offers to the original work of art.

3.2 A RE-STATEMENT OF THE CASE FOR EXTERNAL VENTILATION OF A DOUBLED WINDOW

3.2.1 Introduction

There are continued misunderstandings about the advantages of externally-ventilated externally-protective glazings, and I want to clarify the position in this note. For example, I have been in correspondence with Dr Eva Frodl-Kraft about the translation of her contribution in Section 3.1, and I raised the question of externally-ventilated windows. Her initial reaction was "The most important objective aimed at by protective glazing is to keep the window dry, and this cannot be achieved by allowing the wet external air to penetrate into the cavity". Thus she was under this all-too-common misconception and she has agreed that I should prepare this re-statement of the case for the benefit of everyone.

I perfectly well understand how this misunderstanding arises, because rain occurs outside the building and you go inside it to get out of the rain and be dry! Also, if you use hygrometers to measure the relative humidity of the air, you find that the relative humidity is higher outside the building than inside it! So why does Professor Newton keep saying that there is less water in the outside air?

3.2.2 Why is the air outside the building drier than that inside?

The answer is that during the winter the outside air is colder than the air inside the building, and cold air can "hold" less water than warm air. It is not the relative humidity which is important, but the water content of the air. Meteorologists know this well, but I am indebted to Mr Peter Gibson, of the York Glaziers Trust, for permission to use some measurements which he made inside York Minster (in the North Transept) and outside the South Door, at 13.00 on each of 36 days between 6th October and 22nd December 1975, using a "Whirling Psychrometer". The average values of his 36 readings were:-

	Inside	Outside
Temperature (°C)	14.1	10.9
Relative Humidity (%)	70.1	72.9
Water content of the air (g/m^3)	8.9	7.4
Water vapour pressure (mb)	11.4	9.5

On 3 of the 36 occasions it was warmer outside the Cathedral than inside, but the average temperature was 3.2 degC lower outside the building. On 18 of the 36 occasions, the relative humidity was higher outside the building, and the average outside reading was 72.9%, compared with only 70.1% on the inside, and thus (at first sight) the outside air would seem to be wetter! But air at 14.1°C can hold a maximum of 12.3 grammes of water per cubic metre, and a relative humidity of 70.1% would represent $8.62 g/m^3$ for the inside air. The colder air outside, at 10.9°C, can hold a maximum of only $10.1 g/m^3$, and 72.9% relative humidity would represent only $7.36 g/m^3$. So the outside air would, on the average, have less water in it during these autumn months. Peter Gibson also determined the water contents on these 36 occasions, and on only 6 of them was there more water in the outside air than inside the Minster. His average for the 36 indoor readings was $8.9 g/m^3$ (compared with our calculated figure of 8.6) and his average outside value was $7.4 g/m^3$ (the same as our calculated figure). Thus the cold outside air actually had 14% less water in it, and less water would be carried into the cavity of the window by external ventilation than would be carried there by internal ventilation! It is clear that the difference would be even more marked during the winter in Austria and it would be extremely interesting to know whether anyone has information on this point! The air inside a cathedral is made very wet by the breath of all the people in the congregation and the visitors, and the warmer air can hold more of this water.

3.2.3 Why is it better to ventilate the cavity to the outside?

A full discussion is complicated but there is an excellent account by R.M.E. Diamant in his book "The Internal Environment of Dwellings", published by Hutchinson Educational (178-202 Great Portland Street, London W.1) at £1.50;

Ref. ISBN 0 09 107300 6. Everyone who wants to understand this question should read this book. But put very briefly the warm wetter air from inside the building (when internal ventilation is used) carries so much water into the cavity that condensation will occur on face No.2 (the inside face of the modern glass) on many occasions during the winter, and there must be a wide space (e.g. at least 50 mm) between the two windows so that condensation does not occur also on face No.3 (the outer face of the medieval glass). In the experiment at Sheffield it was found that a gap of more than 100 mm would be required to maintain face No.3 at least 1 degC warmer than face No.2 (see section 2.1.2 of N.L. No.15).

In the case of a cavity which is ventilated to the exterior the reverse situation exists, and the space between the windows should (for a number of practical and aesthetic reasons) be made as small as possible. For example, 10mm would be satisfactory if architects and glaziers can invent a method of mounting two windows so close together!

In winter, during the day, face No.3 will be at least 3 degC warmer than face No.2 even when the sky is clouded over (see Table I on p.7 of N.L. No.16) because the medieval glass contains more iron and manganese than the modern glass and daylight warms it up more than the outside window (see Fig.6 on p.9 of N.L. No.16). If there is some sunshine, face No.3 will be much warmer (see section 2.2.4 on p.9 of N.L. No.16). During the night face No.3 will still be warmer than face No.2 (by at least 1.5 degC - see section 2.1.4 on p.7 of N.L. No.16) because (a) the stonework will have retained heat from the previous day (see section 2.2.2 of N.L. No.16) and (b) the cathedral may have been heated.

Thus condensation will hardly ever occur on face No.3, provided the cavity is ventilated to the outside! Let us consider the worst case (if the weather conditions are steady), when it is raining and the outside air is completely saturated with water (100% relative humidity). But the air will be saturated with respect to its own temperature; face No.3 will be 3 degC warmer; it will be above the dew point and condensation will not occur!

We must not forget that there will be the occasional situation when condensation will occur on the medieval glass (both faces 3 and 4); suppose there has been a period of very cold weather (e.g. sub-zero) and the temperature of the cathedral (its walls and contents also) has fallen to zero, or below. If then a "warm front" arrives, and rain falls when the outside air is much warmer than the building, then the medieval glass would have a temperature below the dew point and condensation would occur on both faces. But we must remember that, under those weather conditions, condensation would also occur on both faces of internally-ventilated glass; the warm wet air from outside would enter the building through the doors and other gaps and condensation would occur everywhere.

As soon as the sun shines, however, face No.3 would warm up very quickly and a current of dry air would pass up the interspace so that the condensation would be dispersed through the external ventilation. In the case of internal ventilation the process would be slower because there would be the mass of condensed moisture throughout the building.

In all of this discussion we must remember that condensation must occur on the medieval glass on some occasions each winter whether we use internal ventilation (isothermal glazing) or whether the space is ventilated to the outside (unless heat is supplied to the cavity by the use of heating wires, and then there would probably be less use of electrical energy if external ventilation were used with 1mm gaps instead of the 50mm gaps needed with internal ventilation). The number of times, during each winter, when condensation must occur with either system (without heating wires) will depend on the geographical location of the cathedral, and the various national meteorological offices may already have the necessary information.

Answers are required as follows:- (a) for isothermal glazing, the water content of the air inside the building (and hence its dew point) and how often the outside temperature is more than 3 degC below the dew point, (b) for externally-ventilated glazing we need to know how often weather conditions lead to the arrival of warm wet air with a dew point at least 3 degC above the temperature of the building on the previous few days.

If these meteorological data are not available, then measurements should be made as in section 3.2.4 below.

3.2.4 What measurements should be collected in the future

Ideally, we need to know how often condensation occurs on the medieval glass with both systems of ventilation. This can be determined in a direct manner by using an incipient condensation gauge and a chart recorder (see items Q,R,S,T in Figs. 1 and 2 of N.L. No.13). This would probably cost about £600 but an integrating condensation recorder can be made by connecting the condensation gauge to a self-starting synchronous clock (these pieces of equipment will be discussed in N.L. No.22).

If this cannot be done, then the water-content of the air should be determined as Peter Gibson did at York Minster, using a "Whirling Psychrometer". That is the best instrument to use but if one cannot be obtained, then a good double-thermometer should be used, one with a "dry" bulb and the other with a "wet" bulb; when readings are taken the air must be fanned vigorously until the "wet" bulb temperature ceases to fall. It should be possible to read the thermometers to 0.1 degC.

Hair hygrometers are not sufficiently reliable for this purpose, and care should be taken when using a recording hygro-thermograph to ensure that it is calibrated frequently, at least once per year.

I greatly hope that arrangements can be made in several cathedrals, or large churches, to collect data like those given in section 3.2.2 above.

3.2.5 Aesthetic problems with externally-protective glazings

The general aesthetic problems have been pointed out in N.L. No.7, section 3. The two which I shall discuss here are the appearance of the window from inside, and the appearance of the Gothic façade from the outside.

Isothermal glazing usually (but not necessarily, see Santa Croce Church and Prato Cathedral, in N.L. No.7, section 9.2) involves moving the medieval window inwards and making it wider and longer so that light does not penetrate around the window at the mullions and the sill. With externally ventilated windows the medieval glass is left in the glazing groove and hence there are no problems with light passing around the edges; it is thus ideal for "rescue conservation".

With isothermal glazing there is no loss of depth of the mullions on the outside, because the modern window is placed in the glazing groove. But the use of external ventilation really demands the modern window to be placed on the outside and there will then be some loss of the depth of the mullions (see the note on page 5 of N.L. No.7). However, the interspace can be made much less than it is at York Minster (65mm) and 10mm would be ideal if architects and glaziers can invent a way of fixing two windows so close together.

3.2.6 Other questions

In my correspondence with Dr Eva Frodl-Kraft she raised two other questions. She says:- (a) "the external air necessarily carries more dust and this will collect in the space" and (b) the external air is "not so balanced as to temperature".

As regards (a) the ventilation gaps at the top and bottom of the lancets should be quite narrow; the experiment at York Minster showed that 1mm gaps would be adequate (see section 2.1.5 on p.7 of N.L. No.16) thus there is little risk of wind blowing dust into the cavity, although gauze should be used to prevent flies from getting in. Here it should be pointed out that the "ventilation" is in fact quite a slow process because it takes place by thermal convection as the window warms up in daylight. As to whether dust may collect in the space, very little dust was found in the space at Bern Minster after 20 years, and all the dust was on face No.2 (presumably because it was colder than face No.3). My guess is that very little dust would enter an externally-ventilated space having 1mm slots, but an answer should eventually be obtainable from the windows at York Minster.

As regards (b), the external air being less uniform in temperature, I am not sure how significant this would be because south-facing windows in sunlight reached 46.5°C in April 1975 in York Minster (section 2.1.3 of N.L. No.16) and this will certainly not be the highest temperature to be reached. Thus I have yet to be convinced that a change of a few degC will be significant. Moreover, the cost of heating oil has risen so greatly that the major cathedrals can no longer be heated continuously in the winter, and the future differences in temperature ranges (as between internal and external ventilation) may become smaller.

3.2.7 Does occasional condensation really matter?

One important question has as yet been ignored, and that is whether occasional condensation actually does harm to medieval glass! It has been assumed (and I have probably been the worst in this respect!) that repeated condensation is dangerous because (theoretically) it produces a strongly alkaline solution just before it dries, and that this can cause serious attack; but does it? I asked M Bettembourg to co-operate in some experiments where 3 kinds of simulated medieval glass were exposed to many cycles of repeated condensation and drying, in his environmental cabinet. These experiments have not yet been reported but M Bettembourg and I agree that the samples show surprisingly little damage! Thus it is possible that repeated condensation (with complete drying in between) is nothing like as harmful as I had always believed! More work must be done when the new series of ten simulated medieval glasses are available.

3.2.8 Comments please!

I hope this rather long account will not only clarify the situation but will spur other readers to contribute to the discussion in one way or another.

3.3 THE RESTORATION OF ANCIENT WINDOWS

An interesting editorial entitled "La restauration des vitraux anciens" has appeared on pages 5-8 of No.31 (1976) of Revue de l'Art. This editorial is wide-ranging and it starts by pointing out that the study of stained glass has recently suffered the loss of three savants:- Jean Lafond, Hans Wentzel and Hans Hahnloser, but the impulse given by these three masters is now bearing its fruits; in the last 5 years 7 Corpus volumes have been added to the 10 which existed in 1970 when Revue de l'Art last reviewed the situation. It then refers to the series of "pre-Corpus" volumes which are being prepared in France in view of the urgency of restoration work because much medieval glass is disappearing before our eyes.

There is then an informed discussion of the process of weathering and of earlier restoration techniques which have had harmful results, including scratching, scraping and the use of acids; some of these were denounced 30 years ago but were still in use until recently. The diversity of compositions of the glass and the presence of painted decoration impose great restraints on the methods of conservation which can be used. However, in the last 20 years the approach has been entirely different and the combination of the expertise of historians, scientists and craftsmen, under the guidance of the Corpus, is altering the whole approach.

Reference was then made to the recent conservation of the west windows at Chartres, the outcry in some quarters, and the press conference held by the Secretary of State for Culture. There is a section about the many earlier changes in these windows, from their escape from the fire of 1194, the many replacements in the 13th century, the great restoration of 1420, other restorations in the 16th, 17th and 19th centuries, and the restorations of 1892-1903, 1918 and 1946, so that the only remaining genuine 12th century head is that of the Prophet Jesse.

In 1973, when the window had been seriously corroded and was in urgent need of re-leading, it was found that the external patina could be removed by a solvent technique (see N.L. No.11, Ref.170 and N.L. No.20, Ref. 220) and the cleaned window was protected by a coating of synthetic resin which could be removed at any time.

The next section describes the now well-known new colour balance of the windows and emphasises that the decrease in the predominance of the blue colour cannot be attributed to the resin coating because it was not applied to the blue glass (which had already resisted atmospheric attack for 800 years).

4 RESEARCH FACILITIES IN EUROPE – PART 3

Item No.4 in News Letters Nos 19 and 20 has now been extended by the inclusion of an organisation, No. 4.11, thus continuing the numbering of the two earlier lists.

4.11 CHARLEROI Institut National du Verre, Boulevard Defontaine, 10, B-6000 CHARLEROI, Belgium. Tel. 71-31.00.41 Telex 51.430 b INAVER.

This institute was founded in 1945 to carry out co-operative research and development work for the Belgian glass industry with financial support from the industry and a grant from the Ministry of Economic Affairs. It can undertake private R & D work for Belgian and foreign glass manufacturers, and it is an official testing house for many national standards organisations for glass tests. The research facilities include all modern physical and chemical analytical equipment; electron microscopy; X-ray fluorescence analysis; atomic absorption spectroscopy; accelerated weathering cabinets; and equipment for measuring the chemical durability of glass. Further information can be obtained from the Director, Pierre Gilard.

5 CHEMICAL ANALYSES OF MEDIEVAL WINDOW GLASSES – PART 1

Throughout the News Letters there has been much discussion about the chemical analyses of medieval glasses and there is now abundant evidence that the weathering characteristics of the glasses are closely related to, if not wholly dependent upon, their chemical composition, especially the silica content, the amount (and perhaps the nature) of the alkali, and the amount of lime. Several laboratories have now been analysing glasses for the last few years and I now have permission to reproduce 125 analyses which are set out in the tables on the next five pages.

5.1 THE KINDS OF ANALYSIS

Each page contains 25 analyses but a few of these are repeat analyses (by different laboratories) on parts of the same piece of glass; in the list of samples, these duplicated analyses are indicated by the two numbers being bracketed together, e.g. (2,3); thus there are fewer than 125 glasses.

Each analysis is reported in three different ways, first as the weight percentages of the various oxides (the usual kind of analysis). Second, the figures have been converted to molar percentages (and rounded to 100%) because it is the molar proportions (rather than the proportions by weight) which control the chemical and physical properties. Third, the "triangular co-ordinates" have been calculated because these seem to be particularly important in understanding the durability characteristics of the glasses (see Ref.205 in N.L. No.17). In the case of high-lead glasses (e.g. Nos 67 and 68) the triangular co-ordinates were not calculated.

5.2 THE PARTICIPATING LABORATORIES

These 125 analyses have been contributed by the following six laboratories (for convenience, the key numbers have also been quoted from Section 4 of News Letters Nos 19 and 20.

ANALYSIS NUMBER		1	2	3	4	5	6	7	8	9	10	11	12	13
LABORATORY		Vienna	St.Hel.	Sheff.	Paris	Oxford	St.Hel	Sheff.	← Vienna →				Sheff.	St.Hel
” Reference		Rouen 3	YORK 228		Aube 3	"York Pink" No 96	YORK 194		Speyer 2	Speyer 3	Rouen 2	Rouen 4	York 195	YORK 229
Colour		green	deep blue		pale blue	pink	purple		violet	light brown	white		pink	green
Weathering		○	○		△	○	○			#	○	○	△	○
Date		⑰	⑫		⑮-⑯	⑫	⑫		⑫	⑫	⑬	⑬	⑫	⑫
WEIGHT PERCENTAGE	SiO_2	63.3	61.7	58.0	61.6	58.4	57.4	58.2	58.21	53.56	56.3	57.1	54.2	52.5
	Na_2O	2.4	12.4	12.0	2.99	1.7	1.8	1.4	0.29	0.37	0.4	0.5	1.6	1.6
	K_2O	4.2	6.4	6.7	10.7	16.9	16.3	17.6	18.10	26.40	14.6	11.4	18.9	17.4
	MgO	3.3	2.2	2.0	4.48	3.0	5.1	5.8	2.82	3.55	7.6	8.6	6.6	5.1
	CaO	11.3	8.5	9.1	12.4	11.8	11.3	11.2	15.15	11.13	13.2	14.3	11.6	11.6
	MnO	–	0.9	?	0.96	0.7	1.2	?	–	–	–	–	?	0.8
	CuO	–	0.15	?	0.034	nil	<0.05	?	–	–	–	–	?	3.0
	ZnO	–	<0.05	0.1	–	nil	<0.05	0.1	–	–	–	–	0.1	0.4
	PbO	–	0.31	–	0.009	–	<0.01	–	–	–	–	–	–	<0.01
	Al_2O_3	2.4	2.8	2.4	0.85	1.5	1.2	1.2	}3.25	}4.10	3.9	3.2	1.0	1.4
	Fe_2O_3	3.1	1.0	1.8	0.51	0.3	0.24	0.3			<1	<1	0.3	0.36
	TiO_2	–	–	–	0.10	0.3	–	–	–	–	–	–	–	–
	P_2O_5	–	2.5	1.3	2.8	4.0	5.0	3.9	–	–	–	–	4.5	5.9
	OTHERS	–	–	–	CoO=0.08 NiO=0.0056	–	–	–	–	–	–	–	–	–
	TOTAL	96.0	99.7	93.4	97.5	98.6	99.9	99.8	97.82	99.11	96.0	95.1	98.8	100.3
MOLAR PERCENTAGE	SiO_2	72.0	65.4	64.9	65.4	64.3	61.6	61.9	63.3	59.4	59.8	59.9	58.4	57.1
	Na_2O	2.7	12.7	13.0	3.1	1.8	1.9	1.5	0.3	0.4	0.4	0.5	1.6	1.7
	K_2O	3.1	4.3	4.8	7.3	11.8	11.2	12.0	12.5	18.7	9.9	7.6	13.0	12.1
	MgO	5.6	3.5	3.4	7.1	4.9	8.1	9.2	4.6	5.9	12.1	13.5	10.6	8.2
	CaO	13.8	9.7	10.9	14.1	13.9	13.0	12.8	17.6	13.2	15.0	16.0	13.4	13.5
	MnO	–	0.6	?	0.9	–	0.8	?	–	–	–	–	?	0.6
	CuO	–	0.1	?	–	–	–	?	–	–	–	–	?	2.5
	ZnO	–	0.1	0.1	–	–	0.1	0.1	–	–	–	–	0.1	0.3
	PbO	–	0.1	–	–	–	–	–	–	–	–	–	–	–
	Al_2O_3	1.6	1.7	1.6	0.5	1.0	0.8	0.8	}1.9	}2.5	2.4	2.0	0.6	0.9
	Fe_2O_3	1.3	0.4	0.8	0.2	0.1	0.1	0.1			<0.4	<0.4	0.1	0.1
	TiO_2	–	–	–	0.1	0.3	–	–	–	–	–	–	–	–
	P_2O_5	–	1.1	0.6	1.3	1.9	2.2	1.7	–	–	–	–	2.0	2.7
	OTHERS	–	–	–	CoO 0.1	–	–	–	–	–	–	–	–	–
	TOTAL	100.1	100.0	100.0	100.1	99.9	100.0	100.1	100.2	100.1	100.0	99.9	99.8	100.0
TRIANGULAR VALUES	"SiO_2"	77.8	70.7	70.1	68.2	67.8	65.0	65.4	67.1	64.4	64.9	64.1	61.8	60.9
	"RO"	19.4	14.3	14.4	22.2	19.2	22.5	22.1	22.2	19.1	27.2	29.7	24.1	25.9
	"R_2O"	2.9	15.0	15.5	9.7	12.9	12.5	12.6	10.9	16.6	7.9	6.1	13.9	13.2

ANALYSIS NUMBER		14	15	16	17	18	19	20	21	22	23	24	25	ANALYSIS NUMBER	
LABORATORY		Sheff.	Vienna	St.Hel	Paris	← Vienna →			Sheff.	← Paris →			Vienna	LABORATORY	
” Reference			Lech Kirche 1	York 196	Houdan 1	Rouen 1	Speyer 4	Lech Kirche 3	York 206	EVREUX Gb	Fa	Ulm 3	Speyer 8	” Reference	
Colour			white	amber	pale green	white	blue	dark green	light green	green		yellow	dark bl. grn	Colour	
Weathering				○	○	○			△	#	#	○	○	Weathering	
Date			⑬	⑫	⑯	⑬	⑫	⑬	⑭	⑬	⑬	⑮	⑫	Date	
WEIGHT PERCENTAGE	SiO_2	49.7	47.93	55.0	60.6	56.4	54.85	43.34	51.6	51.8	51.3	58.5	54.10	SiO_2	WEIGHT PERCENTAGE
	Na_2O	1.1	1.11	1.8	5.87	0.2	0.94	0.13	1.5	2.51	0.32	1.69	1.70	Na_2O	
	K_2O	18.4	18.14	17.1	4.50	14.4	14.90	11.21	18.4	18.0	18.3	6.30	15.90	K_2O	
	MgO	5.4	4.98	5.8	2.29	5.5	3.28	2.16	6.3	7.47	7.86	3.12	4.97	MgO	
	CaO	11.4	21.82	13.5	19.7	16.5	17.40	12.10	13.4	11.5	11.75	21.8	16.33	CaO	
	MnO	?	–	1.2	0.77	–	–	–	?	0.96	1.16	0.79	–	MnO	
	CuO	?	–	<0.05	0.0057	–	–	2.01	?	0.072	0.018	0.006	–	CuO	
	ZnO	0.5	–	<0.05	–	–	–	–	0.1	–	–	–	–	ZnO	
	PbO	–	–	<0.01	0.042	–	–	26.16	–	0.048	0.045	0.018	–	PbO	
	Al_2O_3	1.5	}4.47	1.1	2.95	5.4	}7.60	}2.68	1.4	1.70	4.25	4.34	}7.33	Al_2O_3	
	Fe_2O_3	0.5		0.25	0.86	<1			0.5	0.70	0.71	0.79		Fe_2O_3	
	TiO_2	–	–	–	0.41	–	–	–	–	0.30	0.25	0.33	–	TiO_2	
	P_2O_5	4.6	–	4.1	1.90	–	–	–	4.5	4.17	4.10	2.35	–	P_2O_5	
	OTHERS	–	–	–	CoO=0.005 NiO=0.038 Cr_2O_3=0.0073	–	–	–	CoO – NiO Cr_2O_3	– 0.002 –	0.0013 0.0204 –	0.005 0.038 0.0073	–	OTHERS	
	TOTAL	93.0	98.45	100.0	100.0	98.4	98.97	99.79	97.7	99.2	100.1	100.0	100.33	TOTAL	
MOLAR PERCENTAGE	SiO_2	57.7	51.3	58.4	62.2	59.1	59.1	56.5	56.4	55.5	55.1	60.3	57.2	SiO_2	MOLAR PERCENTAGE
	Na_2O	1.2	1.2	1.9	5.8	0.2	1.0	0.2	1.6	2.6	0.3	1.7	1.7	Na_2O	
	K_2O	13.6	12.4	11.6	3.0	9.7	10.2	9.3	12.8	12.3	12.5	4.2	10.7	K_2O	
	MgO	9.4	8.0	9.2	3.5	8.6	5.2	4.2	10.2	11.9	12.6	4.8	7.8	MgO	
	CaO	14.2	25.0	15.4	21.7	18.6	20.1	16.9	15.7	13.2	13.5	24.1	18.5	CaO	
	MnO	?	–	0.9	0.7	–	–	–	?	0.9	1.0	0.7	–	MnO	
	CuO	?	–	–	–	–	–	2.0	?	0.1	–	0.1	–	CuO	
	ZnO	0.4	–	–	–	–	–	–	0.1	–	–	–	–	ZnO	
	PbO	–	–	–	–	–	–	9.2	–	–	–	–	–	PbO	
	Al_2O_3	1.0	}2.2	0.7	1.8	3.3	}4.4	}1.6	0.9	2.7	1.1	2.7	}4.1	Al_2O_3	
	Fe_2O_3	0.2		0.1	0.3	<0.4			0.2	0.3	0.3	0.3		Fe_2O_3	
	TiO_2	–	–	–	0.3	–	–	–	–	0.3	0.2	0.2	–	TiO_2	
	P_2O_5	2.7	–	0.8	0.8	–	–	–	2.0	1.9	1.9	1.1	–	P_2O_5	
	OTHERS	–	–	–	–	–	–	–	–	–	–	–	–	OTHERS	
	TOTAL	100.4	100.1	100.0	100.1	100.0	100.0	99.9	99.9	100.1	100.1	100.2	100.0	TOTAL	
TRIANGULAR VALUES	"SiO_2"	62.8	55.7	61.1	67.5	66.0	67.9	59.7	60.6	60.5	63.2	67.6	65.4	"SiO_2"	TRIANGULAR VALUES
	"RO"	24.0	33.0	26.0	25.9	27.4	25.3	32.3	26.0	26.1	27.1	29.7	26.3	"RO"	
	"R_2O"	13.6	11.4	12.9	6.7	6.6	6.8	7.9	13.3	13.5	9.8	2.9	8.3	"R_2O"	

		26	27	28	29	30	31	32	33	34	35	36	37	38
ANALYSIS NUMBER		26	27	28	29	30	31	32	33	34	35	36	37	38
LABORATORY		← Paris →		Oxford	← Paris →			← Vienna →				← Paris →		Sheff.
" Reference Colour Weathering Date		Oise 2 deep blue △ C13	Amiens 2 blue violet ○ C13	York Green No 97 green △ C12	Rouen 1 amber ○ C15	l'Aube 13 dark violet △ C15-C16	Amiens 9 emerd green # C13	Maria am G. 1 - ○ 1400	Speyer 5 Ruby △ C12	Maria am G. 3 - △ 1400	Speyer 1 white # C12	Amiens 6 pale green ○ C13	Rouen Ha dark red # C15	York 214 light green △/○ C15
WEIGHT PERCENTAGE	SiO_2	56.1	52.6	51.4	54.0	54.5	53.2	50.7	52.20	49.9	52.05	54.4	49.1	53.8
	Na_2O	0.93	2.29	1.5	2.16	0.30	1.02	0.1	0.69	0.2	0.40	3.15	0.22	2.2
	K_2O	16.1	13.4	16.3	13.8	12.4	14.35	19.9	17.15	18.4	21.10	10.15	19.0	12.2
	MgO	4.05	6.70	6.8	7.56	4.36	5.10	4.0	4.27	3.6	<1	6.73	5.31	8.5
	CaO	14.9	14.4	13.9	15.4	18.1	15.25	18.5	19.10	20.5	21.10	19.5	17.7	19.9
	MnO	0.44	0.85	0.7	0.77	1.91	1.31	—	—	—	—	0.43	1.17	?
	CuO	0.164	0.14	1.8	0.0059	0.009	2.20	—	—	—	—	0.78	0.06	?
	ZnO	—	—	0.3	—	—	—	—	—	—	—	—	—	0.1
	PbO	0.123	0.005	—	0.003	0.009	0.127	—	—	—	—	0.052	0.125	—
	Al_2O_3	1.65	2.0	1.1	2.22	3.7	1.6	3.7	4.07	3.3	5.55	1.9	—	1.1
	Fe_2O_3	1.25	0.65	0.5	0.42	0.60	1.65		2.74			1.00	1.03	0.6
	TiO_2	0.27	0.12	0.4	0.19	0.19	0.22	—	—	—	—	0.275	0.28	—
	P_2O_5	3.60	5.2	4.4	4.03	1.5	3.90	—	—	—	—	4.5	2.68	3.2
	OTHERS	CoO 0.075 NiO 0.025 Cr_2O_3 0.008	0.11 0.11 —		0.0013 0.0108 —	0.072 0.210 —	0.0014 0.0032 —					0.0085 0.0136 —	0.0013 0.0020 —	
	TOTAL	99.7	98.6	99.1	100.6	97.7	99.9	96.9	100.22	95.9	100.20	102.9	96.7	101.6
MOLAR PERCENTAGE	SiO_2	60.3	56.2	55.3	55.9	58.3	56.9	55.7	55.5	55.1	56.1	54.7	53.8	53.8
	Na_2O	1.0	2.4	1.5	2.2	0.3	1.0	0.1	0.7	0.2	0.4	3.1	0.3	2.1
	K_2O	11.1	9.1	11.2	9.1	8.5	9.8	13.9	11.6	12.9	14.5	6.5	13.3	7.8
	MgO	6.5	10.7	10.9	11.7	6.9	8.2	6.5	6.8	5.9	<1	10.1	8.7	12.7
	CaO	17.2	16.5	16.0	17.1	20.8	17.5	21.8	21.7	24.2	24.4	21.0	20.8	21.3
	MnO	0.4	0.8	—	0.7	1.7	1.8	—	—	—	—	0.4	1.1	?
	CuO	0.1	0.1	1.5	—	—	1.1	—	—	—	—	0.6	0.1	?
	ZnO	—	—	0.3	—	—	—	—	—	—	—	—	—	0.1
	PbO	0.1	—	—	—	—	0.1	—	—	—	—	—	0.1	—
	Al_2O_3	1.0	1.3	0.7	1.4	2.3	1.0	1.8	2.5	1.7	3.2	1.1	—	0.7
	Fe_2O_3	0.5	0.3	0.2	0.2	0.3	0.6		1.1			0.4	0.4	0.2
	TiO_2	0.2	0.1	0.3	0.1	0.1	0.2	—	—	—	—	0.2	0.3	1.3
	P_2O_5	1.6	2.4	1.9	1.7	0.7	1.7	—	—	—	—	1.9	1.3	—
	OTHERS	CoO NiO	0.1 0.1			0.1 —								
	TOTAL	100.0	100.1	100.0	100.1	100.0	99.9	99.8	99.9	100.0	100.2	100.0	100.2	100.0
TRIANGULAR VALUES	"SiO_2"	65.1	61.9	59.2	60.9	64.3	62.0	59.3	62.7	58.5	63.5	59.8	56.2	56.9
	"RO"	24.3	28.3	28.2	29.5	29.5	28.7	28.3	28.5	30.1	24.8	32.1	30.8	34.1
	"R_2O"	10.6	9.9	12.6	9.7	6.2	9.2	12.2	8.7	11.4	11.9	8.1	13.2	9.0

		39	40	41	42	43	44	45	46	47	48	49	50	
ANALYSIS NUMBER		39	40	41	42	43	44	45	46	47	48	49	50	ANALYSIS NUMBER
LABORATORY		← Vienna →		Sheff.	Vienna	← Paris →		Vienna	← Sheffield →					LABORATORY
" Reference Colour Weathering Date		Speyer 9 bright green ○ C12	Speyer 10 yellow green ○ C12	York 200 pale green ○ C14	Speyer 7 yellow green # C12	Amiens 11 dark violet ○ C13	Evreux 1 white # C13	Speyer 11 dark green C12	York 202 green △ C14	Austr. acid soluble 44 # -	York 201 ruby △ C14	York 198 light blue # C12	Ely 27 very heavy [illegible] # C14	" Reference Colour Weathering Date
WEIGHT PERCENTAGE	SiO_2	46.45	47.06	50.6	48.70	51.7	49.2	49.80	50.3	45.9	47.1	44.8	44.4	SiO_2
	Na_2O	0.66	0.48	2.2	0.93	0.38	2.70	0.43	3.5	0.6	0.4	0.3	1.0	Na_2O
	K_2O	15.25	14.20	13.3	22.20	11.35	18.5	17.02	10.7	22.9	17.6	18.3	15.2	K_2O
	MgO	2.78	3.43	6.4	2.09	3.71	7.32	3.30	8.0	4.5	4.2	4.0	5.1	MgO
	CaO	19.10	19.00	20.6	20.80	19.7	11.8	24.50	22.6	22.2	25.9	25.2	28.0	CaO
	MnO	—	—	?	—	0.78	0.95	—	?	*?	?	?	0.3	MnO
	CuO	—	—	?	—	0.061	0.056	—	?	—	?	?	—	CuO
	ZnO	—	—	0.1	—	—	—	—	0.1	0.1	0.1	0.2	0.1	ZnO
	PbO	8.31	8.50	—	—	0.187	0.176	—	—	—	?	?	—	PbO
	Al_2O_3	5.30	6.91	2.2	5.40	1.7	3.56	3.65	1.3	*2.2	2.7	2.3	*4.0	Al_2O_3
	Fe_2O_3			1.0		1.2	1.01	1.02	0.6	0.30	0.7	0.9	0.5	Fe_2O_3
	TiO_2	—	—	—	—	0.215	0.27	—	—	*↑	—	?	*↑	TiO_2
	P_2O_5	—	—	4.2	—	4.2	4.25	—	4.4	—	3.2	2.3	—	P_2O_5
	OTHERS					0.075 0.0001 —	0.0013 0.0020 —			BaO 0.6 Li_2O 0.5			0.3 0.5	OTHERS
	TOTAL	97.85	99.58	100.6	100.12	95.3	99.8	99.72	101.6	99.8	101.8	98.3	99.4	TOTAL
MOLAR PERCENTAGE	SiO_2	53.7	53.0	52.6	52.9	57.4	53.2	52.6	50.6	49.4	49.1	48.4	46.8	SiO_2
	Na_2O	0.8	0.5	2.2	1.0	0.4	2.9	0.4	3.4	0.6	0.4	0.3	1.0	Na_2O
	K_2O	11.3	10.2	8.8	15.4	8.0	12.7	11.5	6.9	15.7	11.7	12.6	10.2	K_2O
	MgO	4.8	5.8	9.9	3.4	6.1	11.8	5.2	12.0	7.2	6.5	6.4	8.0	MgO
	CaO	23.7	23.0	22.9	24.2	23.4	13.6	27.8	24.4	25.6	28.9	29.2	31.6	CaO
	MnO	—	—	?	—	0.7	0.8	—	?	—	?	?	—	MnO
	CuO	—	—	?	—	0.1	0.1	—	?	—	?	?	—	CuO
	ZnO	—	—	0.1	—	—	—	—	0.1	—	0.1	0.1	—	ZnO
	PbO	2.6	2.6	—	—	0.1	—	—	—	—	—	—	—	PbO
	Al_2O_3	3.3	4.2	1.4	3.1	1.1	2.3	2.3	0.8	1.4	1.6	1.5	2.5	Al_2O_3
	Fe_2O_3			0.4		0.5	0.4	0.4	0.2	—	0.3	0.4	—	Fe_2O_3
	TiO_2	—	—	—	—	0.2	0.2	—	—	—	—	—	—	TiO_2
	P_2O_5	—	—	1.8	—	1.9	1.9	—	1.8	—	1.5	0.1	—	P_2O_5
	OTHERS					0.1 —								OTHERS
	TOTAL	100.2	99.9	100.1	100.0	100.0	99.9	100.2	100.2	99.9	100.0	99.9	100.1	TOTAL
TRIANGULAR VALUES	"SiO_2"	60.3	61.8	58.0	59.1	62.7	60.7	58.0	54.4	52.2	54.3	53.2	51.8	"SiO_2"
	"RO"	31.1	31.6	32.9	27.6	30.5	26.3	33.0	36.5	32.8	35.5	35.7	39.6	"RO"
	"R_2O"	8.8	6.5	9.2	13.3	6.8	12.9	9.2	9.3	14.9	10.2	11.0	8.7	"R_2O"

* see text.

	ANALYSIS NUMBER	51	52	53	54	55	56	57	58	59
	LABORATORY	PARIS								
	" Reference	Amiens 32	Amiens 30	Le Mans 4	Amiens 31	Saint Denis Ab	Amiens 15	L'Aube 6	Amiens 14	MO-1
	Colour	Clear Blue	Red	Dark Blue	Red	yellow green				
	Weathering	8	△	△	#	#	△	○	△	#
	Date	C13	C13	C13-C15	C13					C15
WEIGHT PERCENTAGE	SiO_2	61.1	53.8	51.7	48.9	50.8	52.5	68.7	50.3	57.0
	Na_2O	0.32	2.78	0.54	0.24	0.34	1.16	13.74	0.43	2.4
	K_2O	13.2	13.6	16.2	22.4	16.1	16.70	1.3	18.6	15.0
	MgO	6.70	6.81	4.49	3.46	4.51	6.37	0.07	5.70	7.2
	CaO	12.4	13.7	14.2	17.8	20.2	11.0	12.1	13.6	12.7
	MnO	1.0	0.8	0.79	1.57	0.24	1.54	0.23	1.08	?
	CuO	0.098	0.28	0.128	0.036	0.013	0.039	0.39	0.21	?
	ZnO	–	–	–	–	–	–	–	–	–
	PbO	0.052	0.068	0.037	0.095	0.002	0.082	0.005	0.243	?
	Al_2O_3	3.2	2.08	2.3	1.76	1.6	0.75	1.8	1.6	1.9
	Fe_2O_3	0.94	0.81	0.90	0.82	0.59	0.65	0.65	0.80	0.23
	TiO_2	0.31	0.33	0.19	0.17	0.23	0.12	0.03	0.085	?
	P_2O_5	2.04	3.77	3.1	1.92	4.72	3.5	0.07	3.4	3.9
	OTHERS	Cr_2O_3 – CoO 0.06 NiO 0.02	0.0019 – 0.0019	– 0.087 0.0046	0.0019 – 0.0019	– 0.0013 0.0204	– 0.063 0.0001	– 0.0085 0.0073	– 0.142 0.0003	– – –
	TOTAL	101.4	98.8	94.7	99.2	99.3	94.5	99.1	96.2	100.3
MOLAR PERCENTAGE	SiO_2	62.7	57.1	58.3	53.6	54.4	58.8	70.3	56.1	64.3
	Na_2O	0.3	2.9	0.6	0.2	0.4	1.3	13.6	0.5	2.6
	K_2O	8.6	9.2	11.7	15.6	11.0	11.9	0.8	13.2	10.8
	MgO	10.2	10.8	7.6	5.6	7.2	10.6	0.1	6.1	3.7
	CaO	13.6	15.6	17.2	20.9	23.2	13.2	13.3	16.3	15.4
	MnO	0.9	0.7	0.8	1.4	0.2	1.5	0.2	0.7	–
	CuO	0.1	0.2	0.1	–	–	–	0.3	0.1	–
	ZnO	–	–	–	–	–	–	–	–	–
	PbO	–	–	–	–	–	–	–	0.1	–
	Al_2O_3	1.9	1.3	1.7	1.1	1.0	0.5	1.1	1.1	1.3
	Fe_2O_3	0.4	0.3	0.4	0.3	0.2	0.3	0.3	0.5	0.1
	TiO_2	0.2	0.3	0.2	0.1	0.2	0.1	–	0.2	–
	P_2O_5	0.9	1.7	1.5	0.9	2.1	1.6	–	1.9	1.9
	OTHERS	–	–	0.1	–	–	0.1	–	0.1	–
	TOTAL	99.8	100.1	100.2	99.7	99.9	99.9	100.0	100.1	100.1
TRIANGULAR VALUES	"SiO_2"	68.4	62.3	64.2	57.4	59.1	62.1	73.1	60.6	69.0
	"RO"	24.8	27.3	25.8	27.9	30.6	25.4	13.9	27.2	19.1
	"R_2O"	6.6	10.5	10.2	14.4	10.2	12.4	13.0	12.3	12.0

	ANALYSIS NUMBER	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
	LABORATORY	VIENNA															
	Lab. Reference	Stift-Heiligenkr.	ST MARTIN MUHLKREIS					Krems Munster	Stift Heiligenkreuz		Strassengel	St Leonhard	Georgskirche - Wiener Neustadt			Wallfahrtskirche str	
			3/5a	3/5b	3/11	3/12	2	2	1	3	1		1	2	3	2	3
	Colour	violet	green	green	pink Violet	blue	green	blue	green	green	yellow	Flashed ruby	yellow	blue	violet	green	blue
	Weathering																
	Date	C12-C14	1400	1400	1400	1400	1400	1450	C12-C14	C12-C14	C14	C14	1600	1600	1600	C14	C14
WEIGHT PERCENTAGE	SiO_2	49.40	45.55	49.03	48.53	50.47	47.26	47.15	34.60	39.10	48.80	48.50	71.30	57.60	56.50	47.95	47.86
	Na_2O	0.27	0.05	0.05	0.05	0.05	0.10	0.15	0.12	0.27	0.62	0.19	5.95	0.65	0.43	0.10	1.08
	K_2O	19.80	19.50	20.23	20.34	19.50	20.23	18.32	9.80	12.90	21.65	21.40	11.05	6.75	6.35	16.45	22.23
	MgO	2.86	3.45	3.62	3.98	3.48	3.48	5.48	1.14	2.20	4.07	3.88	0.54	4.76	4.95	4.08	3.88
	CaO	22.8	22.55	22.71	22.50	22.77	20.85	21.86	5.26	6.90	25.50	21.15	8.55	21.50	21.65	19.54	18.90
	MnO	–	–	–	–	–	–	0.81	–	–	–	–	–	–	–	–	–
	CuO	–	–	–	–	–	–	0.25	–	–	–	–	–	–	–	2.44	–
	ZnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	PbO	–	–	–	–	–	–	0.77	44.74	35.08	–	–	–	–	–	3.68	–
	Al_2O_3	}3.85	3.25	2.90	}3.82	4.50	4.73	2.35	1.67	1.70	}3.25	3.57	2.30	7.16	7.30	4.52	3.22
	Fe_2O_3		3.18	3.05			3.06	1.52	1.81	1.20							
	TiO_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	P_2O_5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	OTHERS						CoO NiO	0.18 0.22									
	TOTAL	98.98	97.53	101.6	99.2	100.8	99.7	99.06	99.1	99.35	103.89	98.69	99.7	98.4	97.2	98.76	97.17
MOLAR PERCENTAGE	SiO_2	53.0	50.2	51.9	52.0	53.3	51.4	50.2	55.8	56.6	49.7	52.5	75.1	60.0	59.6	52.9	52.8
	Na_2O	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.6	0.2	6.0	0.6	0.4	0.1	1.2
	K_2O	13.5	13.7	13.6	13.9	13.1	14.1	12.4	10.1	11.9	14.1	14.8	7.4	4.4	4.2	11.6	15.6
	MgO	4.6	5.7	5.7	6.3	5.5	5.6	8.7	2.7	4.8	6.2	6.3	0.8	7.5	7.7	6.8	6.4
	CaO	26.2	26.6	25.7	25.8	25.8	24.3	24.9	9.1	10.7	27.9	24.5	9.6	24.0	24.4	23.2	22.3
	MnO	–	–	–	–	–	–	0.7	–	–	–	–	–	–	–	–	–
	CuO	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	2.1	–
	ZnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	PbO	–	–	–	–	–	–	0.2	19.4	13.7	–	–	–	–	–	1.2	–
	Al_2O_3	}2.4	3.8	1.8	1.9	2.	4.6	1.5	1.6	1.5	}1.5	1.8	1.1	3.4	3.5	2.3	1.6
	Fe_2O_3			1.2}				0.6	1.1	0.6							
	TiO_2	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	–	–
	P_2O_5	–	–	–	–	–	–	0.2	–	–	–	–	–	–	–	–	–
	OTHERS	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	TOTAL	99.9	100.1	100.0	100.0	100.0	100.1	100.0	100.0	100.2	100.0	100.1	100.0	99.9	99.8	100.2	99.9
TRIANGULAR VALUES	"SiO_2"	57.8	57.8	57.9	55.8	57.7	60.6	54.4	?	?	52.8	56.1	77.3	66.8	66.6	57.5	56.0
	"RO"	30.8	32.3	31.4	32.1	31.3	29.9	35.1			34.0	30.8	10.4	31.5	32.1	33.3	28.7
	"R_2O"	11.3	9.9	10.7	12.1	11.0	9.6	10.5			13.2	13.2	12.3	1.6	1.1	9.4	15.2

ANALYSIS NUMBER		76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	ANALYSIS NUMBER
LABORATORY " Reference Colour Weathering Date		← VIENNA — MUSEUM — FÜR — VÖLKERKUNDE →																							SHEFF.	YORK	LABORATORY cc Reference Colour Weathering Date
		Strass-engel	St. Maria am Gestade				Lilienfeld			Wienhausen Convent					St. Michaelskirche			Heilig-enkr.	York Minster				Phrygia		Stourbridge Dennis Hall		
		4 ruby	4 pale blue	7 pale green	8 yellow	9 ruby	1 white	3 dark green	4 ruby	1	15 pink violet	5 white	24	10	M.1	M.2	M.4	Yellow	deep² blue ○	3 violet	4 white △	5 white	green	yellow	Colourless 176		
		⑭	1420	1350	1400	1420				⑬	⑭	⑯	⑮	⑭	⑭	⑭	⑭	⑫	⑫	⑫	⑭	⑮	⑫	⑫	1770		
WEIGHT PERCENTAGE	SiO_2	50.33	49.86	47.10	50.25	48.60	50.35	47.40	50.10	47.0	47.20	55.5	54.9	46.6	48.02	50.13	50.10	49.87	68.24	59.66	52.75	58.13	67.00	70.00	73.3	68.84	SiO_2
	Na_2O	0.59	0.20	0.18	0.19	0.27	0.66	0.13	0.29	0.04	0.48	2.4	1.4	0.2	0.30	0.32	0.45	0.27	12.81	1.52	1.75	1.62	14.28	12.80	6.0	5.47	Na_2O
	K_2O	21.54	17.84	18.65	17.42	17.85	15.80	15.95	16.08	13.4	16.60	3.3	5.8	19.7	21.65	20.90	20.94	13.96	1.21	10.48	10.48	8.20	1.34	1.17	4.4	4.15	K_2O
	MgO	4.01	3.68	4.35	2.66	4.77	5.55	2.02	4.45	3.7	5.78	4.6	3.8	4.4	2.42	3.99	2.95	4.62	1.78	5.93	7.66	8.36	2.31	2.22	5.0	5.69	MgO
	CaO	18.90	21.30	21.55	21.37	22.90	22.50	10.30	20.30	27.9	22.5	24.7	22.7	23.3	21.00	19.68	19.73	23.21	7.86	13.15	15.18	16.48	9.02	10.48	12.5	11.57	CaO
	MnO	–	–	–	–	–	–	–	–	–	2.26	–	–	–	0.54	1.0	2.0	trace	0.52	1.22	1.15	0.71	trace	trace	–	0.09	MnO
	CuO	–	–	–	–	–	–	2.47	–	–	–	–	–	–	0.12	–	–	0.06	0.22	trace	trace	trace	2.51	trace	–	0.07	CuO
	ZnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.02	ZnO
	PbO	–	–	–	–	–	–	20.11	–	–	–	–	–	–	0.64	–	–	0.35	0.46	trace	trace	trace	–	–	–	0.10	PbO
	Al_2O_3	4.05	2.45	3.55	6.60	1.67	3.48	0.65	7.03	5.5	3.82	4.7	5.2	–	2.88	3.91	3.98	3.90	3.47	3.91	4.12	3.15	1.86	1.10	1.8	1.43	Al_2O_3
	Fe_2O_3					2.65		0.60		0.9	0.66	3.3	1.8	–	2.31			1.30	1.57	0.84	0.95	1.25	1.47	1.53	0.8	0.53	Fe_2O_3
	TiO_2	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	trace	trace	trace	trace	trace	trace	trace	–	–	TiO_2
	P_2O_5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.04	P_2O_5
	OTHER	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	OTHER
	TOTAL	99.32	95.33	95.38	98.49	98.71	98.34	99.6	98.2	98.4	99.30	98.5	95.6	94.2	99.88	98.93	98.15	97.54	98.14	96.71	94.04	97.90	99.79	99.30	103.8	100.0	TOTAL
MOLAR PERCENTAGE	SiO_2	54.4	54.9	52.2	54.9	52.0	53.0	59.5	54.3	49.8	49.5	57.3	58.5	– NOT CALCULATED →	52.5	53.6	53.9	53.2	71.2	63.2	57.0	59.3	68.1	70.7	70.4	69.0	SiO_2
	Na_2O	0.5	0.2	0.2	0.2	0.3	0.7	0.1	0.3	–	0.5	1.9	1.5		0.3	0.3	0.5	0.3	13.0	1.6	1.8	1.6	14.1	12.6	5.6	5.3	Na_2O
	K_2O	14.8	12.5	13.1	12.2	12.0	10.6	12.8	11.1	9.0	11.1	2.2	4.0		15.1	14.3	14.4	9.5	0.8	7.1	7.2	5.4	0.9	0.8	2.7	2.7	K_2O
	MgO	6.4	6.1	7.1	4.4	7.6	8.7	3.8	7.2	5.8	9.0	7.1	6.1		3.9	6.4	4.7	7.3	2.8	9.4	12.3	12.7	3.5	3.3	7.1	8.5	MgO
	CaO	21.9	25.1	25.5	25.0	26.1	25.3	13.9	23.5	31.7	25.3	27.4	25.9		24.6	22.6	22.7	26.5	8.9	14.9	17.6	18.0	9.8	11.3	12.9	12.4	CaO
	MnO	–	–	–	–	–	–	–	–	–	2.0	–	–		0.5	0.9	1.8	–	0.4	1.1	1.1	0.6	–	–	–	0.1	MnO
	CuO	–	–	–	–	–	–	2.3	–	–	–	–	–		0.1	–	–	0.1	0.1	–	–	–	1.9	–	–	0.1	CuO
	ZnO	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	0.0	ZnO
	PbO	–	–	–	–	–	–	6.8	–	–	–	–	–		0.2	–	–	0.1	0.1	–	–	–	–	–	–	0.0	PbO
	Al_2O_3	1.9	1.2	1.8	3.3	1.0	1.7	0.5	3.5	3.4	2.4	2.9	3.3		1.8	1.9	2.0	2.5	2.1	2.4	2.6	1.9	1.1	0.7	1.0	0.8	Al_2O_3
	Fe_2O_3					1.1		0.3		0.4	0.2	1.3	0.7		1.0			0.5	0.6	0.3	0.4	0.5	0.6	0.6	0.3	0.2	Fe_2O_3
	TiO_2	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	TiO_2
	P_2O_5	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	0.9	P_2O_5
	OTHER	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	OTHER
	TOTAL	99.9	100.0	99.9	100.0	100.1	100.0	100.0	99.9	100.1	100.0	100.1	100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	TOTAL
TRIANGULAR VALUES	"SiO_2"	58.2	57.3	55.8	61.5	56.2	56.4	61.1	61.3	57.4	54.7	65.7	66.5	NOT CALCULATED	58.1	57.4	57.9	59.2	76.6	68.6	63.0	64.1	71.5	73.3	73.0	71.9	"SiO_2"
	"RO"	28.3	31.2	32.6	29.4	33.7	34.0	26.8	30.7	37.5	36.3	34.5	32.0		29.3	29.9	29.2	34.0	12.3	25.4	31.0	31.3	15.2	14.6	20.0	21.1	"RO"
	"R_2O"	13.4	11.5	11.5	9.1	10.2	9.6	12.1	7.9	5.2	9.0	0.0	1.5		12.6	12.7	12.9	6.8	11.1	6.0	6.0	4.6	13.3	12.1	7.0	7.0	"R_2O"

ANALYSIS NUMBER		101	102	103	104	105	106	107	108	109	110	111	112	113
LABORATORY		← DEPARTMENT OF PHYSICS UNIVERSITY OF YORK												
		CAMBRIDGE Kings College Chapel		CHARTRES CATHEDRAL					WALLFAHRTSKIRCHE, STRASSENGEL					
„ Reference		184	185	1	2	3	4	5	365 I/6a	366 I/7b	367 I/7b	368 I/7b	369 I/7b	370 I/5a
Colour		white	green	blue	blue	blue	yellow	pink	yellow	dk. blue	bl.grn.	white	violet	Ruby
Weathering				O		O								
Date		C16	C16	C12		C12			mid 14th century					
WEIGHT PERCENTAGE	SiO_2	58.70	60.12	74.7	60.4	70.5	49.8	47.0	45.48	67.75	70.29	66.76	67.42	45.74
	Na_2O	2.96	2.78	9.5	0.7	14.3	0.9	1.5	1.22	9.94	11.58	10.43	6.92	1.16
	K_2O	4.57	4.42	1.2	6.2	1.8	17.1	17.6	24.91	3.13	3.38	1.96	8.58	25.49
	MgO	3.69	3.29	0.6	3.3	0.5	4.2	3.8	3.35	0.10	1.41	0.09	0.31	3.45
	CaO	22.06	21.27	7.9	20.7	8.1	19.8	21.2	20.90	11.08	9.00	13.71	10.80	18.51
	MnO	1.17	0.73	0.7	1.0	0.7	0.7	1.1	0.54	0.12	0.19	0.17	2.46	1.02
	CuO	<0.01	0.80	0.5	<0.01	0.18	<0.01	<0.01	0.10	1.32	0.68	0.27	0.08	0.17
	ZnO	0.04	0.23	0.03	0.03	0.03	0.03	0.02	0.05	0.03	0.02	0.02	0.01	0.05
	PbO	0.05	0.09	0.9	0.6	0.8	<0.01	0.01	<0.01	5.73	2.59	6.41	2.84	0.58
	Al_2O_3	2.19	2.17	1.8	3.2	1.6	1.4	1.2	1.51	0.47	0.55	0.00	0.27	2.07
	Fe_2O_3	0.62	0.38	1.3	0.6	0.8	0.5	0.3	0.30	0.33	0.31	0.18	0.31	0.27
	TiO_2	—	—	—	—	—	—	—	—	—	—	—	—	—
	P_2O_5	3.96	3.73	0.9	3.3	0.8	5.6	6.2	1.66	0.0	0.0	0.0	0.0	1.50
	OTHER	—	—	ø —	ø —	ø —	—	—	—	ø —	ø —	ø —	ø —	—
	TOTAL	100.01	100.01	100.0	100.0	100.1	100.0	99.9	100.03	100.00	100.00	100.00	100.00	100.01
MOLAR PERCENTAGE	SiO_2	60.0	61.6	76.9	62.5	72.4	53.6	50.9	49.3	71.7	72.3	70.2	71.0	50.1
	Na_2O	2.9	2.8	9.5	0.7	14.2	0.9	1.6	1.3	10.2	11.6	10.6	7.1	1.2
	K_2O	3.0	2.9	0.8	4.1	1.2	11.7	12.1	17.2	2.1	2.2	1.3	5.8	17.8
	MgO	5.6	5.0	0.9	5.1	0.8	6.7	6.1	5.4	0.2	2.2	0.1	0.5	5.7
	CaO	24.2	23.3	8.6	22.9	8.9	22.9	24.6	24.3	12.6	9.9	15.5	12.2	21.7
	MnO	1.0	0.6	0.6	0.9	0.6	0.6	1.0	0.5	0.1	0.2	0.2	2.2	1.0
	CuO	0.0	0.6	0.4	0.0	0.1	0.0	0.0	0.1	1.1	0.5	0.2	0.1	0.2
	ZnO	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PbO	0.0	0.0	0.3	0.2	0.2	0.0	0.0	0.0	1.6	0.7	1.8	0.8	0.2
	Al_2O_3	1.3	1.3	1.1	2.0	1.0	0.9	0.8	1.0	0.3	0.3	0.0	0.2	1.3
	Fe_2O_3	0.3	0.1	0.5	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	TiO_2	—	—	—	—	—	—	—	—	—	—	—	—	—
	P_2O_5	1.7	1.6	0.4	1.4	0.3	2.5	2.8	0.8	0.0	0.0	0.0	0.0	0.7
	OTHER	—	—	—	—	—	—	—	—	—	—	—	—	—
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
TRIANGULAR VALUES	"SiO_2"	64.9	66.0	80.5	68.3	75.3	58.3	55.4	52.3	72.5	73.1	70.4	71.6	53.6
	"RO"	30.8	29.7	10.8	29.1	10.6	30.2	31.8	30.3	15.6	13.5	17.8	15.8	28.8
	"R_2O"	4.3	4.3	8.7	2.6	14.1	11.5	12.8	17.4	11.9	13.4	11.8	12.6	17.6

114	115	116	117	118	119	120	121	122	123	124	125	ANALYSIS NUMBER	
											→	LABORATORY	
	choir window N.I		HEILIGENKREUZ choir window N.V			COVENTRY		ELY CATHEDRAL LADY CHAPEL					
371 I/4b	372 I/3b	373 I/5c	374	375	376	287	288	283	284	285	286	„ Reference	
bright green	mid blue	grey violet	yellow	white	green			45 LH		green		Colour	
						*	*	#	O	O	#	Weathering	
			1290			C15		14th century				Date	
44.76	46.47	46.41	44.43	44.70	41.64	52.78	51.55	44.65	55.00	53.58	43.45	SiO_2	WEIGHT PERCENTAGE
0.74	0.78	0.71	0.79	0.50	0.00	3.44	2.97	1.02	2.23	2.59	1.86	Na_2O	
24.52	26.57	23.68	23.02	20.40	12.63	6.20	6.75	19.50	13.18	13.19	15.64	K_2O	
3.09	3.45	3.45	3.82	3.26	0.96	3.66	3.80	4.17	6.86	5.11	4.21	MgO	
20.23	18.22	20.18	23.49	25.50	6.55	24.51	26.92	25.07	14.79	12.79	25.56	CaO	
0.87	0.96	1.28	0.44	0.62	0.31	1.49	1.17	1.87	1.11	0.87	0.44	MnO	
0.15	0.19	0.10	0.11	0.09	2.18	0.21	0.08	0.10	0.16	3.80	0.08	CuO	
0.05	0.07	0.04	0.01	<0.01	0.11	0.05	0.03	0.02	0.06	0.37	0.04	ZnO	
1.06	0.06	0.65	0.13	0.80	33.2	—	—	—	—	—	—	PbO	
1.17	1.54	1.24	1.34	1.71	0.49	2.16	1.37	0.69	1.09	2.31	1.38	Al_2O_3	
1.82	0.28	0.41	0.26	0.30	0.19	0.70	0.36	0.20	0.49	0.78	0.63	Fe_2O_3	
—	—	—	—	—	—	—	—	—	—	—	—	TiO_2	
1.54	1.46	1.85	2.16	2.12	1.73	4.80	5.00	2.71	5.04	4.62	6.72	P_2O_5	
—	—	—	—	—	ø —	—	—	—	—	—	—	OTHER	
100.00	100.05	100.00	100.00	100.00	99.99	100.00	100.00	100.00	100.01	100.01	100.01	TOTAL	
49.4	50.8	50.5	47.8	48.0	59.3	54.5	52.9	47.3	57.4	57.4	46.6	SiO_2	MOLAR PERCENTAGE
0.8	0.8	0.7	0.8	0.5	0.0	3.5	3.0	1.0	2.3	2.7	1.9	Na_2O	
17.3	18.5	16.4	15.8	14.0	11.5	4.1	4.4	13.2	8.8	9.0	10.7	K_2O	
5.1	5.6	5.6	6.1	5.2	2.0	5.6	5.8	6.6	10.7	8.2	6.7	MgO	
23.9	21.3	23.5	27.0	29.2	10.0	27.1	29.6	28.4	16.6	14.6	29.4	CaO	
0.8	0.9	1.2	0.4	0.6	0.4	1.3	1.0	1.7	1.0	0.8	0.4	MnO	
0.1	0.2	0.1	0.1	0.1	2.4	0.2	0.1	0.1	0.1	3.1	0.1	CuO	
0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	ZnO	
0.3	0.0	0.2	0.0	0.2	12.8	—	—	—	—	—	—	PbO	
0.8	1.0	0.8	0.9	1.1	0.4	1.3	0.8	0.4	0.7	1.5	0.9	Al_2O_3	
0.8	0.1	0.2	0.1	0.1	0.1	0.3	0.2	0.1	0.2	0.3	0.3	Fe_2O_3	
—	—	—	—	—	—	—	—	—	—	—	—	TiO_2	
0.7	0.7	0.8	1.0	1.0	1.0	2.1	2.2	1.2	2.2	2.1	3.0	P_2O_5	
—	—	—	—	—	—	—	—	—	—	—	—	OTHER	
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	TOTAL	
53.3	53.7	53.3	50.8	51.4	?	59.8	57.1	49.5	61.4	63.1	52.0	"SiO_2"	TRIANGULAR VALUES
30.2	28.1	30.6	33.6	35.3		34.2	36.5	36.8	28.4	27.0	36.6	"RO"	
16.5	18.2	16.1	15.6	13.3		6.0	6.4	13.7	10.2	9.9	11.4	"R_2O"	

ø = there was inadequate surface-preparation of these samples and the results are not completely reliable.
* = these samples showed much spontaneous surface fracturing.

Vienna (4.9)	57 analyses	≠
York (4.4)	26 "	(not from York Minster)*
Paris (4.7)	23 "	
Sheffield (4.8)	13 "	ø
Pilkington Brothers, St. Helens	4 "	
Oxford (4.2)	2 "	

Notes:-

≠ these analyses were carried out by "Wet" chemistry.

* York has also carried out large numbers of analyses on glasses from York Minster, but they are not included here because they will form part of a PhD thesis; they will become available when the work is complete.

ø these analyses were carried out by X-ray fluorescence but they were not corrected for inter-element effects, except for Nos 47, 50 and 99 which were determined by "wet" chemistry.

All the participating laboratories are warmly thanked for their co-operation.

Dr R.H. Brill, of Corning Museum of Glass (4.5), has carried out many analyses of medieval glasses, and 19 of them (8 from York, 5 from Ulm and 6 from Avignon) have been published in the Journal of Glass Studies 1970, 12, 185-192.

5.3 THE VARIABILITY OF THE RESULTS

As would be expected from the "normal"(!) variation between the results from different laboratories, there are marked variations between the results from tests on the same samples. The analyses also differ in the various ways in which the weight-percentage totals differ from 100%. If the total is greater than 100%, the difference represents the cumulative error of measurement. If the total is less than 100% the difference represents these errors of measurement, plus the possibility that certain oxides were present but they were not analysed. However, a total of exactly 100% is not necessarily a guarantee of accuracy in the analyses; for example, the results from York (4.4) are obtained from a computer which automatically brings the total to 100%.

In the tables the symbol "-" means "not looked for"; the symbol "?" means that the oxide is known to be present but it was not measured (for example the X-ray fluorescence analyses from Sheffield (4.8) showed the presence of copper and zinc but there were no "standards" available for determining the amounts of these oxides); the word "nil" (analysis No.5) shows that these oxides, if present, were below the level of detection. In analysis No.47 the MnO and the TiO_2 contents are included in the 2.2% for Al_2O_3; in No.50 the TiO_2 is included in the 4.0% for Al_2O_3. The Paris laboratories (4.7) generally determined the amounts of CoO, NiO and Cr_2O_3 but the other laboratories did not do so, although many of them recorded the presence of "trace elements" which have been ignored in the tables.

5.4 THE WARNINGS!

I think I should include two warnings: (1) that the colour of a piece of glass is not necessarily any guide to its composition even if the pieces come from the same window; for example, it is only a small proportion of the 12th century blue glass from York Minster which is a soda glass (see section 5.2 of N.L. No.20) and similarly two of the three pieces of 12th century blue glass from Chartres (Nos 103 and 105) were high-soda glasses whereas the other (No.104) was a potash glass. Similarly, all the 12th century green glasses reported in Ref.129 of the British Academy Bibliography could not have been melted in the same crucible, although all four pieces of pink glass might have come from the same crucible. My own opinion is that the old glaziers chose their pieces of glass for their colour-match only, and the pieces need not have been made in the same crucible, nor by the same glass-maker, nor in the same country, nor even in the same century if (as now) glass was re-used and (re-)painted at a later date.

(2) My second "warning" concerns the very durable high-soda glasses which have recently attracted so much interest. I fear that there may be a tendency for readers to associate "good durability" with "high soda", but it should be kept in mind (at least for the present) that all of these glasses also have only a moderate amount of lime. Thus it seems to me to be more likely that the good durability may be the result of the moderate lime content, rather than the soda content. There are eight glasses in the tables which have more than 10% by weight of soda (Nos 2, 57, 93, 97, 98, 105, 110 and 111) and their lime contents range from 7.9% to 13.7%. I realise that in simple glasses, such as those which Professor El Shamy used, potash glasses are much less durable than soda glasses but I still have reservations as to whether that comparison can be extended to complex glasses such as our medieval ones.

5.5 THE DURABILITY OF THE GLASSES

The arrangement of the glasses in the tables should be explained because Nos 1-59 are those with the same numbers discussed in Fig.2 on p.32 of Verres et Réfractaires, Volume 30, 1976. In the later tables, e.g. Nos 101-125, they are arranged in groups from the same laboratory. In most cases it has been possible to indicate the general weathering characteristics of the glass by means of three symbols:- "O" = shiny surface, apparently unaltered; "∆" = pitted surface; # = crusted surface.

5.6 THE SOURCES OF THE GLASSES

The samples were derived from five countries, as follows:-

AUSTRIA - 60 samples

Georgskirche, Wiener-Neustadt: 71,72,73
Kremsmunster: 66
Lechkirche: 15,20
Lilienfeld: 81,82,83
St Leonhard: 70
St Maria-am-Gestade: 32,34,77,78,79,80
St Martin Muhlkreis: 61,62,63,64,65
St Michaelskirche, Vienna: 89,90,91
Speyer: 8,9,19,25,33,35,39,40,42,45
Stift. Heiligenkreuz: 60,67,68,92,117,118,119
  (Nos 117,118,119 are from the ornamental
  choir window N.V, 1290)
Strassengel, Wallfahrtskirche: 69,74,75,76,
  108,109,110,111,112,113,114,115,116
  (Nos 108-116 are from the christ cycle
  window, choir No.1, mid 14th century)
Wienhausen: 84, 85, 86, 87, 88
An undesignated, acid-soluble sample: 47

FRANCE - 31 samples

Amiens: 27,31,36,43,51,52,54,56,58
l'Aube: 4,30,57
Chartres: 103,104,105,106,107
Evreux: 22,23,44
Houdun: 17
Le Mans: 53
Mo..... : 59
Oise: 26
Rouen: 1,10,11,18,29,37
St Denis: 55

GERMANY - 1 sample

Ulm: 24

TURKEY - 2 samples

Phrygia: 97,98 (from Uşak-Selçikler)

UNITED KINGDOM - 31 samples

Cambridge, Kings College: 101,102
Coventry, St Michaels Cathedral: 120,121
Ely Cathedral, Lady Chapel: 50,122,123,124,125
  (Nos 122 and 123 are adjacent pieces from
  the same panel; 122 is heavily crusted and
  123 is uncrusted)
Stourbridge, Dennis Hall: 99,100
York Minster: (2,3)5,(6,7)12,(13,14)16,21,28,
  38,41,46,48,49,93,94,95,96

6 NEW ABSTRACTS

227. ADAMS, P.B. (1974) "Crack propagation in annealed glass during exposure to water". Proc. 10th Int. Cong. Glass, Kyoto, July 1974, 11-16 to 11-23 and 15-100.

The possibility of stress-corrosion occurring in glass was first proposed in 1958 and it is now generally accepted that glass can crack when exposed to water because the water reacts with the glass to break the chemical bonds at the tip of the crack. In the past it was assumed that the glass had to be under tension; if the applied tension was great enough, the crack would grow and the glass would break but if the tension was not high enough the attack by the water would cause rounding of the tip, crack growth would not occur, and the glass would be strengthened.

The author shows that this statement is not always true and that water can cause cracks to propagate in certain glasses even though there is no pre-existing tensile stress. It appears that these glasses can hydrate, causing them to swell so that local stresses are produced and cracks can form and grow.

This paper should be consulted by anyone who is proposing to undertake research on the spontaneous cracking of medieval glasses, because the author describes exactly the same phenomenon, i.e. the development of conchoidal fractures from which a chip of glass is dislodged. Having made that statement it is nevertheless quite difficult to draw any immediate conclusions from this report which are of direct value to persons concerned with the conservation of surface-fractured glasses. Adams found that glasses which have poor durability did not crack, apparently because corrosion of the surface then proceeds more rapidly than cracking. Some glasses which were tested at 50°C in water, and also in an atmosphere with 98% relative humidity, cracked more rapidly in the 98% humidity, perhaps because some solution (removal of flaws) may have occurred in the water. Thus any attempts to keep such glasses free from liquid water may not necessarily be successful in stopping the cracking. The author states "A flaw is absolutely necessary to initiate cracking."; if this is true, and the cracks occur only on the outer surface of the glass (i.e. on the unpainted surface of stained glass) there might be the possibility of polishing the surface to remove flaws but a high degree of polishing would probably be required (the author actually tried polishing with 4-micron diamond paste, and found that no cracking occurred, whereas coarser techniques did cause cracks); even then one could not be sure whether flaws might be re-created during further exposure to the weather.

228. ANON (1976) "La restauration des vitraux anciens" (the restoration of ancient windows). An editorial on pages 5-8 of No.31 of Revue de l'Art. This is abstracted as item 3.3. above.

229. ENGLE, Anita (1973) "A semantic approach to glass history". Readings in glass history, No.1, pages 81-84.

The author points out that the early glassmakers formed close craft communities which used special terms, and these may have left their trace in the places where glassmaking was practised. Glassmakers along the Phoenician coast in the 1st to 6th centuries were using terms similar to those used in Babylonia in the 7th century B.C. A study of 16th century Italian glassmaking texts makes it seem possible that some of the early glassmaking families of Europe may have originated in areas where Aramaic was spoken. The author also lists some Hebrew glassmaking words which have Aramaic or Syriac origins.

230. ENGLE, Anita (1973) "Some aspects of trade with Syria in the crusading period". Readings in Glass History, No.2, pages 36-47.

Between 1098 and 1110 Genoa sent six naval expeditions to Syria in support of the Crusades and, in return, were granted colonial holdings along the coast of Syria. Exports of glass from Acre and from Tyre (both places were regarded as one unit) were in the hands of the Genoese. Colonies of Levantines were also present in Genoa and the article lists some of the many trading relationships up to 1189.

231. GASPARETTO, A. (1974) "Verres Venitiens du Moyen Age" (Medieval Venetian glass). Proc. 10th Int. Cong. Glass, Kyoto, July 1974, 9-21 to 9-29 and 15-90.

This article is primarily concerned with portions of Venetian tableware which have been found in excavations in Bohemia, Corinth, Holland, Hungary, Switzerland, Yugoslavia, etc. Medieval window glass is not mentioned but there is a discussion (on pages 9-27 and 9-28) of developments in trade after the conquest of Constantinople in 1204 and their bearing on design of glassware found in many places, including Old Sarum and Knaresborough (in Britain), Liège, Rouen, Stargebow (Holland).

232. HENCH, L.L. (1974) "Biomedical applications and glass corrosion". Proc. 10th Int. Cong. Glass, Kyoto, July 1974, 9-30 to 9-41 and 15-90.

This article is mainly concerned with the development of special glasses which are compatible with human body tissues but, as part of the need to gain an understanding of those problems, there is a general review of corrosion processes on glass surfaces, and of methods of "characterising" glass surfaces which have been in contact with humidity, or a liquid environment. It was found possible to alter the surface composition and microstructure of glasses by using suitable surface treatment.

The nature of the corrosion film was first studied using highly sophisticated techniques (EMPA, SEM, XRF, AES, etc.) which have disadvantages which he lists on p.9-36. However, recent studies have shown that infrared reflection spectroscopy can be used to analyse the surface films formed on glass during corrosion (presumably including weathering), and it would seem that this technique should be considered in planning future work in University-type laboratories.

Some of the glasses used in these studies are reminiscient of medieval high-lime, low-silica glasses, except that they contain soda instead of potash. For example, No.4555 contains 45% silica, 24.5% soda, 24.5% lime, and 6.0% phosphorus pentoxide (P_2O_5). He claims that sufficient P_2O_5 has been added "to prevent rapid deterioration of the chain-like glass structure". In the presence of water a silica-rich gel film is produced on the surface due to the loss of sodium ions, and this is followed by a layer rich in calcium phosphate which "develops within and on top of the silica-rich layer".

233. JOVANOVIĆ, M.A. and ZALAR, R. (1974) "Einige Möglichkeiten zu verbesserung der chemischen Beständigkeit der Glasoberfläche" (Some possibilities of improving the chemical resistance of glass surfaces). Proc. 10th Int. Cong. Glass, Kyoto, July 1974, 9-100 to 9-104.

The authors discuss the formation of the silica-rich layer on weathered glass surfaces and consider that it should be a "protective layer" against further weathering. However, they found that it was porous and hence does not prevent alkali ion-exchange in the unaltered glass below it. They found, however, that they could consolidate the silica-rich layer by heating it under pressure in an autoclave, for 1 hour at 300°C and 50 atmospheres. The resultant skin was then 20 times more durable than the untreated one, and its micro-hardness had also increased by 45%.

(Note by RGN - this interesting conclusion, although useless as a conservation technique, underlines some of the problems in producing a "protective layer" by simple means. It is frequently stated that flame-finished glass surfaces have a "protective skin" on the surface. This may be true for a year or two but there seems to be no evidence that such protective skins have a worthwhile long-term effect on the resistance of the glass.)

234. YAMAMOTO, H. and ISOBE, S. (1974) "Compositional change during electron microprobe analysis of glasses" Proc. 10th Int. Cong. Glass, Kyoto, July 1974, 9-1 to 9-6 and 15-7.

The authors draw attention to some dangers which may be encountered when using some of the modern "non-destructive" methods of chemical analysis of glasses, using "black-boxes". When using the electron microprobe, the impact of the electrons needed for analysing glasses can cause the results to be wrong. This impact of the electrons produces some evolution of non-bridging oxygen atoms and the electric field produced by the electrons causes alkali ions to move away from the surface. As this technique analyses only the surface layer of the glass, the migration of alkali ions from the surface can have serious consequences on the analytical results. In some cases an opposite effect seems to occur but, in either case, there is a risk of obtaining wrong results. Another complication, of a rather technical nature, is that the silicon K_β fluorescence line can change its position, which shows that the structure of the glass becomes denser as a result of the electron bombardment.