St Michael and All Angels' Church, Thornhill
East Window of the Savile Chapel

19th October 2008
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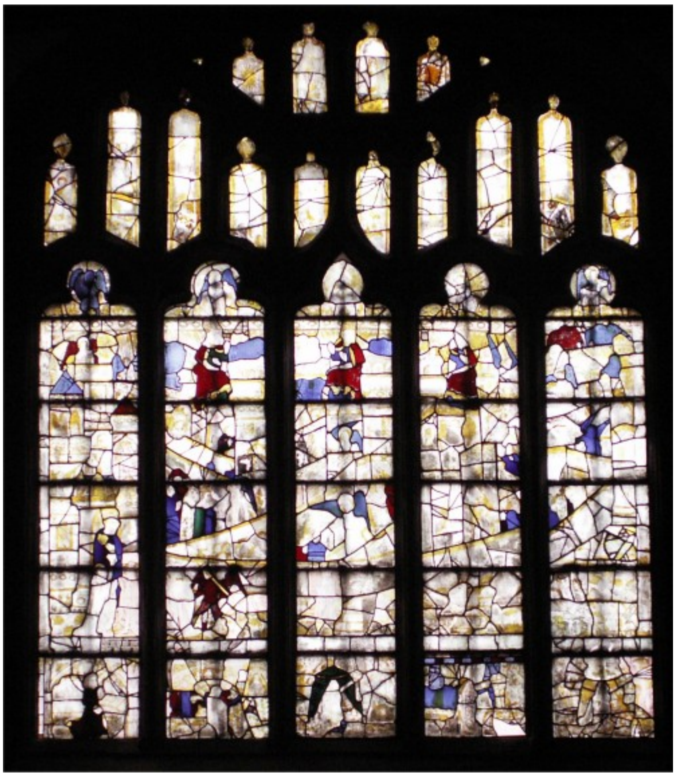
Introduction

On Thursday 2nd October at the invitation of Stained Glass Conservators Jonathan and Ruth Cooke I visited the church at Thornhill and examined the glass of the East window of the Savile Chapel. The examination was limited to visual examination of the glass aided by using a hand lens and by the use of a digital camera to take close-up photographs.



Initial reaction

Overall, when viewed from inside the chapel the window glass appears to be in a very poor state. It was noticeable that the many of the clear glass pieces were damaged and had lost much of the original art work: by contrast, the coloured glass pieces (particularly the blue coloured pieces) appear to be almost unscathed. Immediately one begins to think of differences in chemical composition between these glasses as being a key part of the situation.

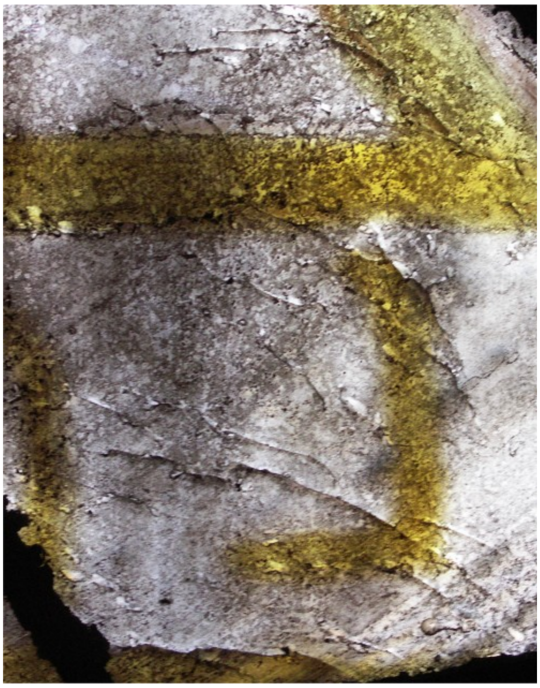
More detailed observations of the interior surfaces

Hand lens examination of the worst affected clear glass pieces in the lower part of the window revealed a rough surface on a scale of perhaps 0.4mm or so, not 'cobbled' because there was visible angularity to the roughness, but with the sharp edges of the angularity somewhat rounded.

severely damaged surface of a piece of clear glass

Less severely damaged pieces showed rather random cracking quite unlike the traditional stress fracture pattern generated when for example a stone strikes an annealed window. One of the blue pieces showed this effect – the cracks are predominantly linear radiating outward from the assumed impact site. The clear glass pieces exhibited more randomly orientated cracks which interestingly showed rounding of the crack edges at the glass surface.

Radial crack pattern on a piece of blue glass indicative of impact damage.



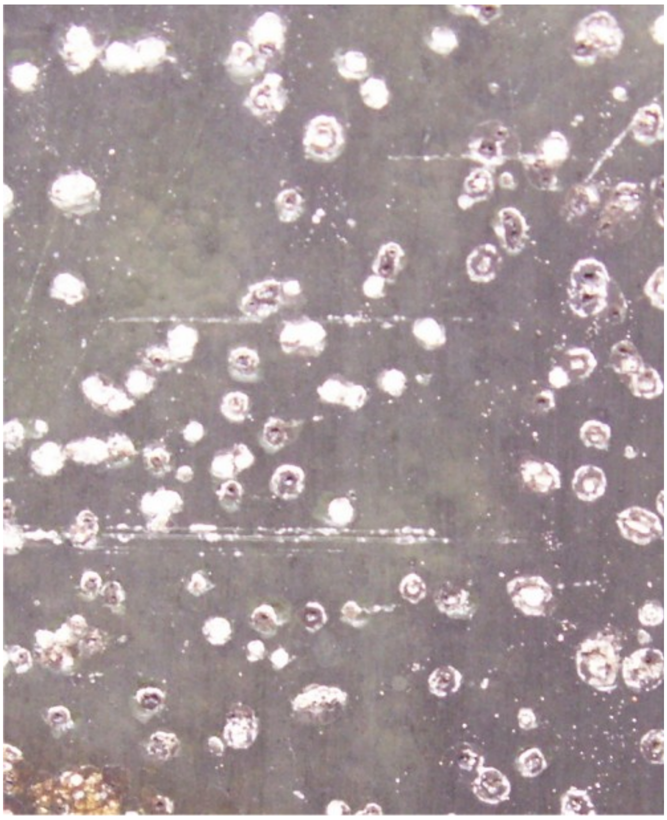
Rather more randomly distributed cracks visible on a piece of clear glass with silver stain.

Detail of some cracks on a piece of clear glass with silver stain – it appears that the "jaws" of the cracks are somewhat rounded.

Observations of the exterior surfaces

The exterior surfaces presented a very different behaviour, with much less evidence of cracking and with roughly circular corrosion pits present to a greater or lesser extent.

Exterior surface, showing corrosion pits perhaps 0.5mm in diameter but little evidence of cracking. To the right of the lead it is clear that the cracks visible are on the interior surface and are viewed through the thickness of the glass.



Detail of the circular corrosion pits on the exterior surface. In some instances the pitting had become so severe that the corrosion pits began to overlap.

Some Conclusions

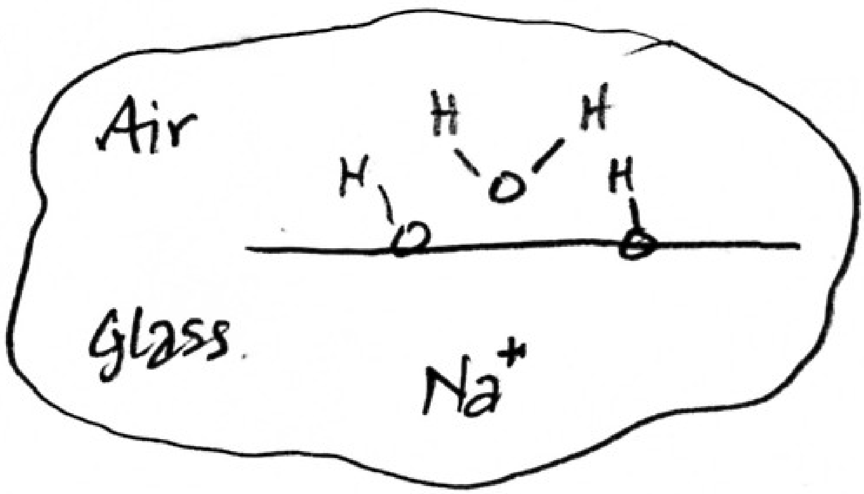
At this stage some tentative conclusions may be drawn. To confirm or refute these would involve expenditure on chemical analysis and other tests of a destructive nature.

- The composition of the affected clear glass is sensitive to moisture attack
- Severe degradation is on the interior surface and not on the exterior surfaces, so explanations involving exposure to an external fire are highly unlikely.
- I believe the damage on the interior surfaces to be the result of moisture attack
- Much of the original glass surface has been lost due to spalling: what remains is much altered chemically
- For the majority of affected pieces the cracking is so deep that there must be doubts about their physical integrity and their ability to withstand the trauma of removal for conservation.
- The in-situ prognosis is that these pieces are vulnerable to wind pressure pulses or serious vibration. The moisture attack will proceed even if no condensation is seen. That attack may be minimised (other things being equal) by allowing air to flow over the glass surfaces.
- Protective glazing which caused stagnancy in the air next to the glass would be likely to accelerate the moisture attack.
- Whilst irreversible in-situ conservation measures (I think of the injection of polymeric materials) might confer improved mechanical stability, one is doubtful of the value of carrying out such work when so much of the original material has been already irreversibly damaged.

Appendix – some explanatory notes

I am indebted to Dr Sarah Fearn (Imperial College, London) and Dr Paul Warren (Pilkington Group Limited) for their helpful discussions regarding these observations on the Thornhill window.

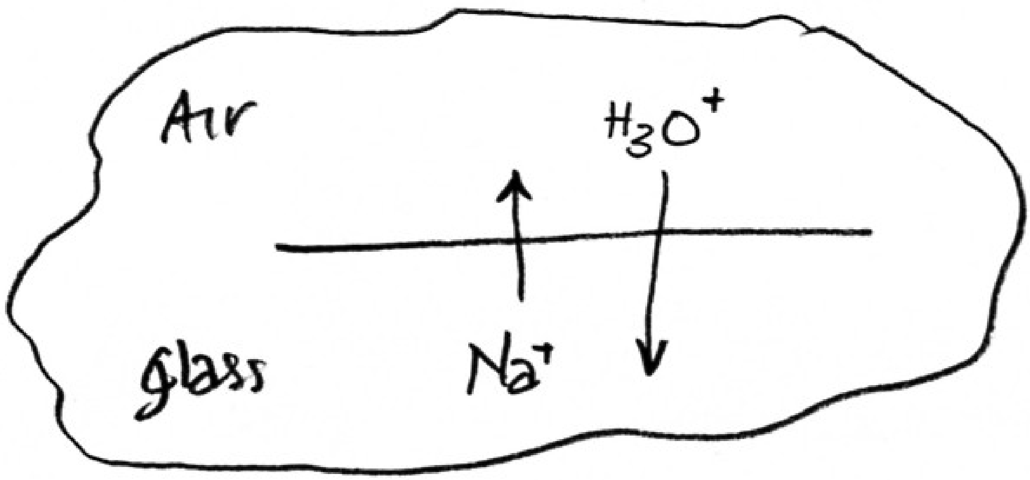
These notes outline some possible mechanisms of moisture attack on the interior surfaces of the Savile Chapel East Window. The degraded pieces have deteriorated markedly and over virtually all of the exposed surface, in marked contrast to the discrete pits seen on the exterior surfaces. Dr Fearn's work (most recently reported in a paper presented at the Society of Glass Technology conference in Cambridge, in September 2008) shows that even in the absence of condensation events, sensitive glasses can be attacked by moisture in the air. Because of the nature of the glass surface at the molecular level, atmospheric moisture is adsorbed to form a layer over the whole surface, possibly only one or two molecules thick.



Sketch 1: the glass surface, showing an adsorbed water molecule and, within the glass, a sodium ion

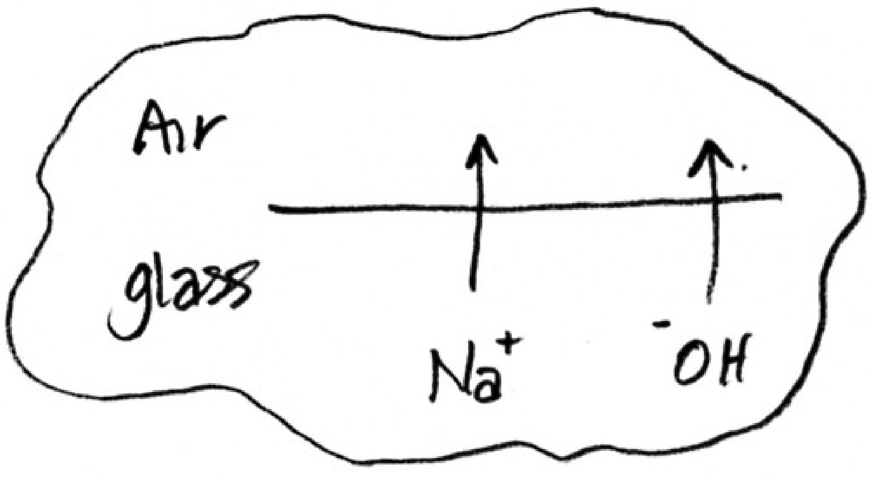
Water molecules occasionally break apart, H_2O becoming H^+ and OH^- for a while. H^+ is very aggressive, instantly commandeering another water molecule to become H_3O^+ which is capable of burrowing into the glass, thereby allowing a sodium ion Na^+ to escape from the glass and come to the surface. The two ions swap over as indicated in Sketch 2 below.

Whilst the explanation of what happens next is based on Dr Fearn's careful measurements, it is somewhat conjectural and has not yet been properly tested. Nevertheless, it makes sense of what has been observed in museum cases and in architectural contexts.



Sketch 2: the exchange of sodium in the glass with water at the surface

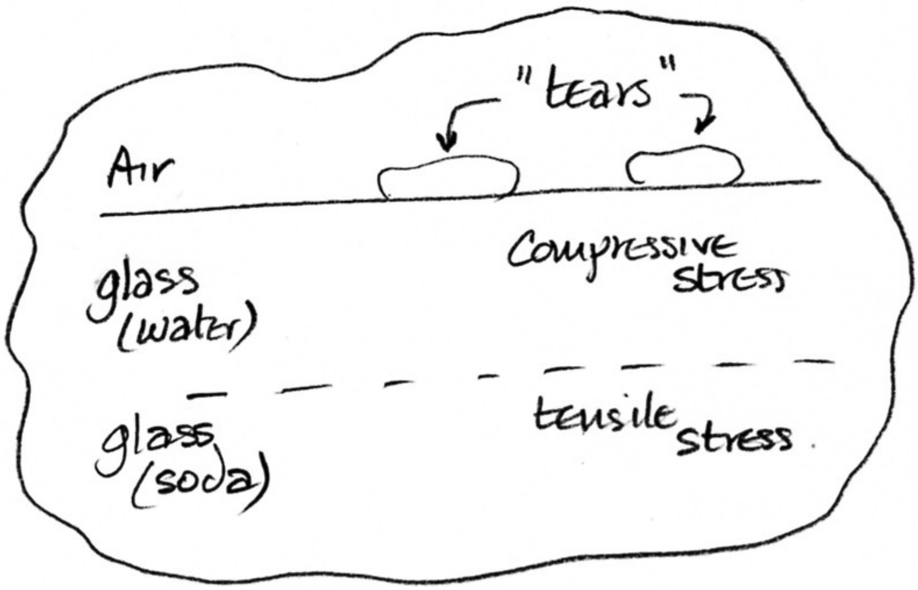
Dr Fearn's measurements indicate that for every hydrogen atom which remains in the glass, three sodium atoms are lost at the surface. An explanation of this is that the H_3O^+ ion in the glass reacts with the network of silicon and oxygen atoms which makes up the molecular framework of the glass, creating OH^- ions. These negative ions can balance the positive sodium ions if they move along with them, so pairs of Na^+ and OH^- ions can diffuse up to the surface and are lost from the glass structure.



Sketch 3: co-diffusion of positive sodium ions and negative hydroxyl ions to the glass surface

Two things then happen. The sodium hydroxide which accumulates at the glass surface serves as a focal point which attracts water – ultimately in the form of visible droplets of moisture. Certain sensitive glass artefacts in museum cases exhibit this phenomenon, know to curators as "weeping" glass disease. In all probability the same thing happens in context of architectural glass, but that is much less easily seen.

The second thing which happens is that stresses start to build up in the glass because of these chemical changes. When water diffuses into the glass surface and replaces sodium, the density of the hydrated layer is reduced because of the changes this causes in the molecular network. The layer tries to expand, but it can't because it is anchored to the unchanged layer beneath.

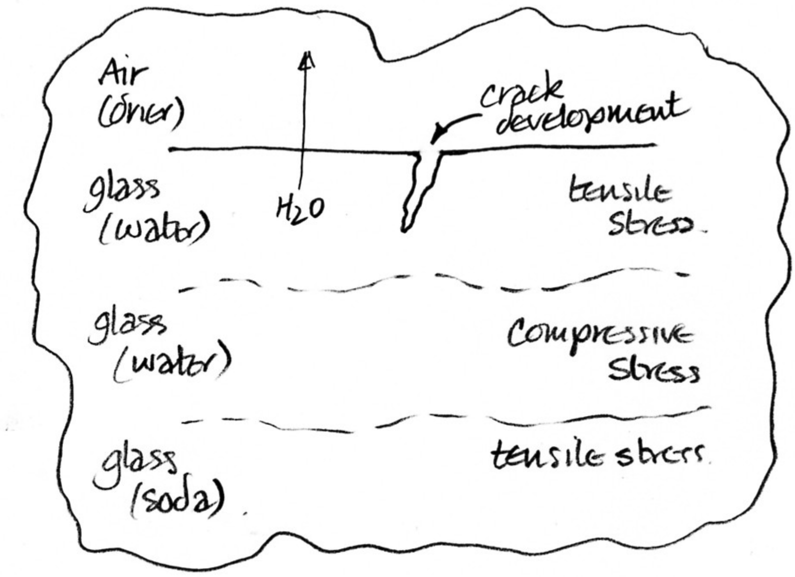


Sketch 4: development of tears on the surface and stress within the layers of the glass

As a result, the surface layer has a compressive stress set up in it, and there is a balancing tensile stress in the unchanged layer beneath. This stress distribution is rather like that in thermally tempered glass: the compressive stress at the surface helps prevent cracking occurring.

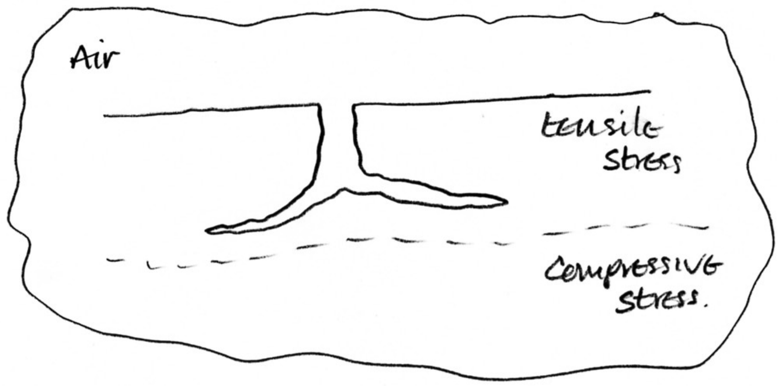
Whilst the moisture content of the atmosphere remains constant, all is well. The dangerous moment is when the surrounding air dries out. The surface layer of glass loses water to the air above, and as it does so it starts to shrink. Again, the layers of glass are anchored to one another, so the surface of the glass starts to experience a tensile stress. In that circumstance microscopic flaws start to open up, turning into small cracks which grow sideways along the surface and downwards into the glass. Sketch 5 depicts this in a schematic fashion.

In a museum context, this becomes visible as a very fine network of cracks extending over the surface of the artefact – known as "cryzzling". I believe that the Thornhill glass must have passed through this stage in the past.



Sketch 5: loss of water from the hydrated layer causes tensile stress in the surface which encourages cracks to grow

Beneath the surface layer there is still a layer lower down which has not lost water and which is still under compression. As the growing cracks extend downwards they respond to this changing stress condition and are deflected, bifurcating and starting to run parallel with the surfaces. Sketch 6 attempts to illustrate this.



Sketch 6: developing cracks being deflected by the prevailing stress fields in the glass

Inevitably as these sideways extensions to the cracks develop, some will meet up. In the end, fragments of surface glass will become completely separated from the bulk, falling off as little shell-shaped pieces. This process is known as "shelling" or "spalling", and it results in complete and irreversible loss of the surface glass, leaving behind scoop-shaped fractures known as "conchoidal" fractures.

Visually the badly affected pieces of glass in the Savile Chapel East Window show this appearance over most of their interior-facing surfaces. One would expect that this process would leave a jagged surface with sharp ridges between the hollows, but careful examination of the panes with a hand lens show that these ridges are rounded off at the tops. The most likely explanation of that is that the attack by atmospheric moisture has been continuing for many years and so the original shape features have become blunted.

This rationalisation leaves us with some conclusions:

- We need not look for condensation events to explain the attack of the interior-facing surfaces by atmospheric moisture
- The argument from chemistry leads to an explanation of cracks which bend around rather than progressing right through the glass thickness, explaining the spalled surface seen on the East Window glass
- The worst affected panes have lost nearly all of the original glass surface and all of the artwork created on that surface by the glass artists
- Damage is irreversible and irretrievable
- The moisture attack on the interior-facing surfaces cannot be halted by any realistic measures
- The ongoing development of networks of cracks will at some stage result in the loss of physical integrity of the affected panes
- The status quo may be preserved for a while by protecting the glass from impact, from wind-induced stresses and from excessive vibration.